OCT 12 1925

Vol. VIII, No. 5. *PSYCHOLOGICAL REVIEW PUBLICATIONS* OCTOBER, 1925

Journal of Experimental Psychology

EDITED BY

JOHN B. WATSON, NEW YORK CITY
HOWARD C. WARREN, PRINCETON UNIVERSITY (*Review*)
SHEPHERD I. FRANZ, UNIV. OF CALIF., SO. BR. (*Monographs*)
MADISON BENTLEY, UNIVERSITY OF ILLINOIS (*Index*) AND
S. W. FERNBERGER, UNIVERSITY OF PENNSYLVANIA (*Bulletin*)

ADVISORY EDITORS

H. A. CARR, UNIVERSITY OF CHICAGO; RAYMOND DODGE, WESLEYAN UNIVERSITY; KNIGHT DUNLAP, THE JOHNS HOPKINS UNIVERSITY; H. S. LANGFELD, PRINCETON UNIVERSITY; E. L. THORNDIKE, COLUMBIA UNIVERSITY.

CONTENTS

A Continuous Multiple Choice Reaction Apparatus: CARL N. REXROAD 325

Class Results with Spaced and Unspaced Memorizing: KATE GORDON 337

Photographic Recording of Eye Movements in the Reading of Chinese in Vertical and Horizontal Axes: Method and Preliminary Results: W. R. MILES AND EUGENE SHEN 344

On the Effects of the Loss of Sleep: THOMAS FISTER WEISKOTTEN 363

An Experimental Study on Retinal Sensitivity and Discrimination for Purple under Different Degrees of Intensity of Stimulation: FRANKLIN O. SMITH 381

PUBLISHED BI-MONTHLY BY
PSYCHOLOGICAL REVIEW COMPANY
PRINCE AND LEMON STREETS, LANCASTER, PA., AND PRINCETON, N. J.

Entered as second-class matter, July 1, 1920, at the post-office at Lancaster, Pa.

Psychological Review Publications

EDITED BY

HOWARD C. WARREN, PRINCETON UNIVERSITY (*Review*)
JOHN B. WATSON, 244 MADISON AVE., NEW YORK (*J. of Exp. Psych.*)
SHEPHERD I. FRANZ, UNIV. OF CALIF., SO. BR. (*Monographs*)
MADISON BENTLEY, UNIVERSITY OF ILLINOIS (*Index*)
S. W. FERNBERGER, UNIVERSITY OF PENNSYLVANIA (*Bulletin*)
WITH THE CO-OPERATION OF
MANY DISTINGUISHED PSYCHOLOGISTS

PSYCHOLOGICAL REVIEW

containing original contributions only, appears bimonthly, January, March, May, July, September, and November, the six numbers comprising a volume of about 480 pages.

PSYCHOLOGICAL BULLETIN

containing abstracts, critical reviews, of books and articles, psychological news and notes, university notices, and announcements, appears monthly, the annual volume comprising about 720 pages. Special issues of the BULLETIN consist of general reviews of recent work in some department of psychology.

JOURNAL OF EXPERIMENTAL PSYCHOLOGY

containing original contributions of an experimental character, appears bimonthly, February, April, June, August, October, and December, the six numbers comprising a volume of about 480 pages.

PSYCHOLOGICAL INDEX

is a compendious bibliography of books, monographs, and articles upon psychological and cognate topics that have appeared during the year. The INDEX is issued annually in May, and may be subscribed for in connection with the periodicals above, or purchased separately.

PSYCHOLOGICAL MONOGRAPHS

consist of longer researches or treatises or collections of laboratory studies which it is important to publish promptly and as units. The price of single numbers varies according to their size. The MONOGRAPHS appear at irregular intervals and are gathered into volumes of about 500 pages.

Philosophical Monographs: a series of treatises more philosophical in character.
Library of Genetic Science and Philosophy: a series of bound volumes.

ANNUAL SUBSCRIPTION RATES

Review: $5.00 (Foreign, $5.25). **Review and Bulletin:** $9.50 (Foreign, $10.00)
Journal: $5.00 (Foreign, $5.25). **Review and Journal:** $9.00 (Foreign, $9.50)
Bulletin: $5.50 (Foreign, $5.75). **Journal and Bulletin:** $9.50 (Foreign, $10.00)
Any one of above with **Index:** $1.50 additional.
Review, Bulletin, and Journal: $14.00 (Foreign, $14.75).
Review, Bulletin, Journal, and Index: $15.00 (Foreign, $15.75).
Current Numbers: Review or **Journal,** $1.00; **Bulletin,** 60c; **Index,** $2.00
Psychological Monographs: $6.00 per volume (Foreign, $6.30).
Current Issues: prices vary according to size.

Subscriptions, orders, and business communications may be **sent direct** to the

PRINCETON, N. J. OFFICE

PSYCHOLOGICAL REVIEW COMPANY

FOREIGN AGENTS: G. E. STECHERT & CO., London (2 Star Yard, Cary St., W.C.) Paris (16, rue de Condé)

Journal of
Experimental Psychology

VOL. VIII., No. 5 October, 1925

A CONTINUOUS MULTIPLE CHOICE REACTION APPARATUS

BY CARL N. REXROAD

Ohio State University

Several pieces of apparatus that may be included in the general class of continuous multiple choice reaction apparatus have been developed and used in various psychological laboratories. The first of these was Seashore's 'Psychergograph,' devised in 1902. Since then Morgan (1), McComas (2), Pressey (3), Bair (4), Coover and Angell (5), and Hansen (6) have devised apparatus of this kind. Hansen gives a brief statement of the nature and accomplishments of each (except those of Pressey and Bair) and also points out the close relation of the type of behavior called for by these apparatus to that called for in card sorting, form substitution, cancellation, and maze performance.

The essential advantage of these apparatus over the simpler Wundt multiple choice apparatus is that the presentation of the stimuli is continuous. This saves the experimenter the labor and time of setting the apparatus for each presentation and also modifies somewhat the nature of the subject's task, a modification which for certain investigations is quite desirable.

The possibility of developing one apparatus that would have been suitable for the particular investigations referred to above, and would be suitable for like investigations which may be pursued in the future naturally suggests itself. The apparatus to be reported was developed with this possibility

in view, as well as to meet the immediate demand of an investigation in which the writer was interested.[1]

The several demands made on such an apparatus may be listed as follows:

A. Demands imposed for any one given performance.

(1) A number of stimuli are to be used (usually four or five).

(2) Each stimulus must have its own particular reaction.

(3) The succeeding stimulus must follow immediately either (*a*) any reaction whether right or wrong, or (*b*) only right reactions.

(4) The stimuli must continue to succeed each other for as long as desired.

(5) The order of appearance of the stimuli should be such that it can not be detected by the subject even after much experience with it. This involves (*a*) an order that may be started or stopped at any point, and since the order for mathematical and mechanical reasons must after a time repeat itself to meet condition (4), this involves also (*b*) an order that is long with no clue as to when it does start to repeat itself.

(6) A full and objective record of the performance should be made, a record which should not involve a great amount of labor in reading.

(7) The apparatus itself must be mechanically dependable.

B. Demands which may be imposed at different performances in one investigation or in different investigations.

The apparatus should provide for making:

(1) Any one of the reactions the right reaction for any one of the stimuli, *i.e.*, it should allow the use of different 'codes.'

It should make possible the use of

(2) Various sets of stimuli, *e.g.*, a set of color stimuli or a set of a sound stimuli.

It should make possible the use of

(3) Various sets of reactions.

[1] Developed in the Yale Laboratory, and used in the research leading to the Ph.D. degree. The title of the Dissertation is: 'The Effect of Electric Shock Administered for Inaccuracy in Continuous Multiple Choice Reactions.'

The apparatus to be described meets the above demands and also a further special demand imposed by the writer's investigation. This special demand was that the apparatus make possible the automatic delivery of an electric shock for wrong reaction.

In the writer's investigation a set of five color stimuli was used, and the reactions were made by pressing one of the five keys.

The keys are arranged for the five fingers of the right hand. Each key is made after the pattern of the Dunlap Chronoscope master key. Closing the upper contact (*K*, Plate 3) requires a stroke of about $\frac{3}{8}$ inch and closing the lower contact (*K'*, Plate 3) requires a further stroke of about $\frac{1}{8}$ inch.

All stimuli are shown on a piece of ground glass $\frac{3}{4}$ by $1\frac{1}{2}$ inch. A 75-watt type C (nitrogen filled) light is used as a common light source. Filter gelatin is used to obtain the different stimuli. The gelatines used are violet-red, clear, green, orange, and blue. All are equalized as to intensity of the light passing through them. (This equalization was made subjectively only. Two colorblind individuals who reported as subjects were unable to discriminate between them.) These gelatines are mounted equidistant on an aluminum disc, and the disc so mounted that in revolving on its shaft, it will bring the gelatines in the order above given successively between the light source and the ground glass. Between the disc and the ground glass is a shutter which in operation is closed while the disc is rotating and open while the disc is held in position. The shaft carrying the color disc is coupled into the control, or main apparatus, at Cp plate 1 and has its position and rotation controlled from this source.

The power applied to this control apparatus consists of a 1 10 H. P. 3400 r. p. m. motor belted with a 1 (*D*) to 9 (*L*) ratio to the cone reducing pulley *RP* the outside diameter of which is 9 inches. Pulley *RP* is belted from its inside diameter 2.25 inches (*D*) to the drive pulley *DP* (*L*) which is 2 inches in diameter (9–8 ratio), with weighted idler control *I*. Idler friction may be adjusted by varying the position and

size of the weight on the notched supporting arm of the idler pulley *I*.

The shaft *CP* of the drive pulley *DP* is the one to which the color disc shaft is coupled and it is geared to shaft *X* at point *Y* with a 1–6 ratio. Shaft *X* carries two five-point rotating switches *RS* and *RS'*, a detailed description of which will be given later. Shaft *X* is also geared to the large escapement gear *G* with gear *G'*. Gear *G'* is a 25 tooth, 20 pitch spur gear, and gear *G* is a 180 tooth, 20 pitch spur gear.

Movement of gear *G* is controlled by the escapement solenoids *M* and *M'* through the escapement pins *EP* and *EP'*. These pins are rod extensions of the solenoid plungers and are rigidly connected by the stabilizing rod *SR* which contains a dialectric and which passes directly through the center of hangar *H''*. The connections between rod *SR* and the two escapement pins *EP* and *EP'* are made by thumb screws *T* and *T'* which are attached midway between the escapement pin hangars *H* and *H'* and the solenoids *M* and *M'*. The thumb screws *T* and *T'* are so set as to form eccentric movement of *EP* and *EP'*, which movement is controlled by alternate activation of solenoids *M* and *M'*.

In the periphera of gear *G*, inserted parallel (=) to the gear plane and ⅛ inch below the trough of the gear are 23 pegs *Pg* ⅛ inch by ½ inch. When solenoid *M* is activated, the pegs clear its escapement pin *EP*. This permits gear *G* to turn by means of the friction applied on the drive pulley *DP*. Activation of *M* by means of the stabilizing rod *SR* also draws escapement pin *EP'* into position so that it will engage the next peg which presents itself by rotation of gear *G*. The engagement of this peg by *EP'* stops the rotation of gear *G* until *M'* is activated. Activation of solenoid *M'* will produce movement of *EP'*, *SR*, and *EP* similarly but in the opposite direction.

When escapement pin *EP* engages a peg, it is in contact through this peg with brush *EB*, and when *EP'* engages a peg, it is in contact through the peg with brush *EB'*. One lead of solenoid *M* goes to brush *EB* and one lead of *M'* to *EB'*. This arrangement alternates the circuit between the two solenoids.

The brushes *EB* and *EB'* are supported from the yoke castings *H* and *H'* but insulated from them. The castings *H* and *H'* serve also as supports for the solenoids *M* and *M'* as well as hangars for the escapement pins *EP* and *EP'*. They are insulated from the base but not from *EP* and *EP'*.

The distance traveled by gear *G* due to activation of solenoid *M* or *M'* is determined by the spacing of the pegs *Pg*. This distance determines the distance traveled of shaft *X* and of shaft *CP* which carries the color disc. 1/5 of a revolution of the color disc brings into position for presentation the adjacent stimulus. For purposes of explanation this amount of rotation will be called a unit movement. For shaft *X* this unit is 1/30 (1/5 x 1/6) of a revolution and for gear *G* this unit is 1/216 (1/30 x 25/180) of a revolution or in terms of teeth is 5/6 of a tooth.

To secure a random presentation of the stimuli, some movements are necessarily one unit movements or what would amount to the same thing 6 unit movements, some 2 (or 7) units, some 3, some 4, and some 5. For mechanical reasons 6 and 7 unit movements, with the exception of one 2 unit movement, were employed in place of one and two unit movements.

The following order of units was adopted: 4–5–3–4–4–3–2–6–6–5–6–7–5–4–6–3–3–5–7–4–7–3–6. The pegs *Pg*, however, could not be spaced on gear *G* in the above order as the engagement of the pegs is alternately diametric. Securing the proper spacing necessitates only a simple calculation from the above table. Arbitrarily calling the first peg inserted peg one, the next would be placed 9 (4 plus 5) units or 45/6 teeth away, the next 7 (3 plus 4) units from the second, or 16 (9 plus 7) units from the first. To avoid cumulative error, all calculations were made from the first peg. The distance of each peg from the first calculated in this way is: 9–16–23–31–42–55–64–73–81–92–102–112–120–128–133–145–156–168–178–184–196–207 units, leaving 9 units between the last and first peg.

The movements allowed by this spacing accounts for 23 presentations. When, however, peg one is engaged the second

time, the stimulus presented is different from that when it was engaged the first time. The reason for this is obvious from the following consideration. Peg one is used a second time after a half revolution of gear *G*. This amount of revolution of gear *G* equals 3 3/5 (1/2 x 180/25) revolutions of shaft *X* and 21 3/5 (3 3/5 x 6) revolutions of shaft *CP*. The color presented then by the second using of the pegs is a color three units from the one presented by the first using of the pegs. The color presented on the sixth using of the peg will be the same as on the first using.

The complete presentation order together with the units of movement involved is given below:

	4	5	3	4	4	3	2	6	6	5	6	7	5	4	6	3	3	5	7	4	7	3	6
	R	B	B	G	W	R	O	R	W	G	G	O	R	R	B	R	O	W	W	O	G	B	G
3	O	G	G	R	B	O	W	O	B	R	R	W	O	O	G	O	W	B	B	W	R	G	R
3	W	R	R	O	G	W	B	W	G	O	O	B	W	W	R	W	B	G	G	B	O	R	O
3	B	O	O	W	R	B	G	B	R	W	W	G	B	B	O	B	G	R	R	G	W	O	W
3	G	W	W	B	O	G	R	G	O	B	B	R	G	G	W	G	R	O	O	R	B	W	B
3	R	etc.																					

The apparatus then makes 115 presentations before repeating and in these 115 presentations no three stimuli appear together twice, and every stimulus is presented an equal number of times.

The next part of the apparatus to be considered is that part whereby only one of the subject's five keys will close the circuit through the escapement solenoids *M* or *M'* when a given stimulus is presented. This condition is secured by introducing a rotating switch *RS'* into the circuit between the keys and the solenoids *M* and *M'*. The rotor of this switch is mounted on shaft *X* and is designated *RS'* on Plate 1 (the outside rotor). It is constructed of ½ inch fiber 4 inches in diameter with six 3/16 brass inlaid contacts *S'* which are equilaterally spaced. In addition to the inlaid contacts *S'* the rotor has a 1½ inch shoulder commutator which with brush *RC'* serves as a common constant contact between the brush binding post *CL* and the inlaid contacts. (The wire connecting the inlaid contacts can be seen on Plate 1.)

A brush support *BS* is constructed of ½ inch fiber and has a diameter of 6 inches. This support *BS* holds besides the brush *RC'* five equally spaced brushes *B'* which rest on rotor *RS'*. Each brush is a one inch spring brass strip inserted at right angles in the end of a ¼ inch brass rod. The brass rod in turn is inserted into the brush support *BS* ½ inch from the periphera. Contact is made with the rod by screwing a binding post *P'* through at right angles to the rod as shown in the cut. The binding post also serves to keep the brush securely in position.

The rotor *RS'* is adjusted on shaft *X* so that when a peg holds the shaft from moving one of the brushes, *B'* will be in contact with one of the inlaid contacts *S'*. A unit movement (1/30 of a revolution) of this shaft brings the adjacent brush brush into contact. (If there were but one inlaid contact, 1/5 of a revolution would make this change, but since there are six inlaid contacts, only 1/6 this amount of movement is required.) This means that each one of the five brushes *B'* will correspond to one of the five stimuli inasmuch as it is the only one of the brushes in contact when that stimulus is presented.

The circuit of the escapement solenoids *M* and *M'* may now be followed out on Plate 3. From plus 110 v. d. c. a lead goes to one side of the lower contacts of all five keys K'. As shown the stimulus being presented calls for reaction on Key K'_2. The closing of this key completes the circuit through the binding post *P'*, through brush *B'*, through the brass inlaid contact, through the shoulder commutator, through brush *RC'* to binding post *Cl'*. Closing the experimentor's short key *Ke* also completes the circuit from + 110 v. d. c. to Cl'. (On Plate 1 one lead of each solenoid is shown going from post *CL'*. These magnet leads were taken later from a separate binding post *CL* on Plate 3.) From *Cl'* (Plate 3) a lead goes through the closed contact points of a pony relay 6, through a 100 unit resistance to binding post *CL*. From *CL* a lead goes to one side of each of the solenoids *M* and *M'*. From each solenoid the other lead goes to its own brush *EB* or *EB'*. One of the brushes will be in contact

with a peg (as shown brush *EB* of solenoid *M*). The circuit is completed through the peg to the escapement pin *EP* and through its hangar *H* to a binding post screwed into this hangar. A lead *Pc* is taken from this binding post through one unit of the apparatus shown on Plate 2 [1] to the negative 110 v. d. c. If the pin *EP'* of solenoid *M'* is in contact with a peg, the circuit is completed from binding post *CL* through solenoid *M'* through its brush *EB'* through the peg, through its brush *EB'* through the peg, through the escapement pin *EP'* to the binding post of hangar *H'*. From hangar *H'* by lead *Pb* through the other unit of the apparatus shown in Plate 2, the circuit is completed to the negative 110 v. d. c.

The circuit for recording errors will next be considered. The simplest scheme would have been to have used a rotating switch so that all but one of its five brushes would have been in contact. This possibility was discarded in favor of one that would give a detailed graphic record using only five markers.

A rotating switch *RS* exactly like the escapement circuit rotating switch *RS'* makes this possible. This rotor *RS* is set on shaft *X* so that any given inlaid contact is one tenth out of phase with its corresponding contact on rotor *RS'*. (This change in phase is made only for convenience in inserting the brushes *B* into the brush support *BS*.)

The circuit passing through this rotating switch *RS* may be designated as the presention-recording circuit and may be followed out on Plate 3. Starting with the plus 110 v. d. c. the circuit goes to junction point *J*. From *J* there are five parallel circuits to the five brushes *B* of the rotating switch. Each circuit passes through a 75-watt resistance and the magnet of a marker. The markers are designated 1, 2, 3, 4, and 5 for their respective circuits. The brush which corresponds to the stimulus being presented will be in contact with an inlaid contact of the rotor *RS*. As shown the brush which gets its lead from marker 2 is in contact. From *J*

[1] The photographic Plate 2 with the description of the apparatus shown by it is not included here. This piece of apparatus is a device for administering an electric shock when the subject's reactions are slower than an arbitrarily set time. Leads *Pb* and *Pc* may be considered as going directly to − 110 v. d. c.

then the circuit is completed through 75 watts resistance, through marker 2, through post *P*, through brush *B*, through inlaid contacts, through the shoulder commutator, through brush *RC*, through pony relay 5 to the binding post *EP* of the control apparatus. This binding post is screwed into the base to which gear *G* is grounded and in this manner the circuit is completed to escapement pin *EP* or *EP'* depending on which is engaging a peg. As shown the circuit is completed to *EP* and from here by lead *Pc*, through apparatus shown on Plate 2 to the negative 110 v. d. c. If *EP'* were in contact the circuit would be completed by lead *Pb* through apparatus shown on Plate 2 to the negative 110 v. d. c. This circuit is broken at *EP* or *EP'* during movement from one presentation to the next but is complete through the marker corresponding to the stimulus being presented so long as the stimulus remains. The stimulus being presented and the time taken to react to it is in this way graphically recorded.

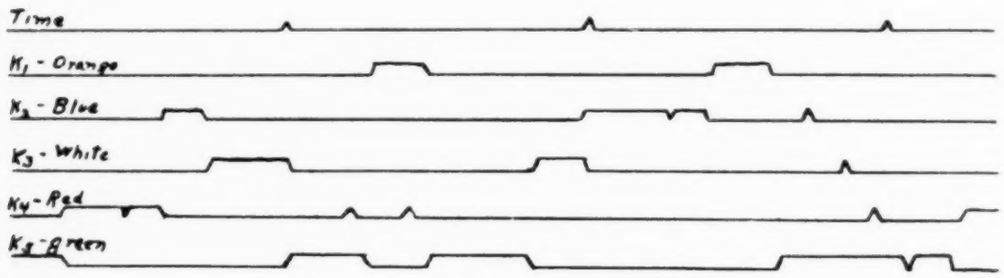
A circuit leading through the contact points of relay 5 of this circuit operates the shutter magnet *A*.

For recording errors, each of the leads from the markers 1, 2, 3, 4, and 5, in addition to going to one of the brushes of the rotating switch *RS*, is taken also to the upper contact of one of the keys *K* (as shown the lead from marker 1 is taken to key K_1, that from marker 2 to K_2, etc.). An error for the presentation conditions shown would be closing of any key other than K_2. Closing any one of these keys, for example K_1 would complete the circuit from plus 110 v. d. c. through point *J* through 75 watts resistance, through marker 1, through K_1 to the common lead for the upper set of key contacts *K*. This lead is taken through the contact points (*c*) of relay 3, through relay 4, and by way of one side of the circuit from *RC* to relay 5. From relay 5 the circuit is completed to the negative 110 v. d. c. as previously described. Closing of any key other than the key corresponding to the stimulus being presented will activate the marker for that key and also activate relay 4.

A circuit taken through the contact points of relay 4 activates an electrically operated counter *E* which counts all

errors no matter on what key they are made. Closing the correct key does not activate relay 4 as the parallel circuit through the rotor has negligible resistance.

The activation of the markers as explained will produce a graphic record which will show what stimulus is presented, the time taken to react to it, and the errors made in response to it. An actual record is reproduced below.



The upper or time line marks every five seconds. The speed of the drum is so adjusted that one second equals one centimeter on the record. This record shows that the colors were presented in the order G R R B W G O G W B B O G G R. Key 4 was closed incorrectly for a green stimulus and also incorrectly for an orange stimulus. Keys 2, 3, and 4 were incorrectly closed for the green stimulus at a later time. The time taken to react in each case can be secured by measuring the distance the recording point remains out of its rest position.

There are two conditions present in the apparatus as thus far explained that need to be eliminated. Since a stimulus may follow itself, keeping the key closed in response to the stimulus on its first presentation would release it on its second presentation. This possibility is eliminated by leading the escapement circuit through the contact points of relay 6 (Plate 3). If the key is kept closed and the stimulus that follows is a different stimulus, then an error would be recorded unjustly against the subject. This possibility is eliminated by leading the error circuit through the contact points of relay 3.

The initial activation of relay 3 is secured by a circuit from binding post *CL'* shunted around the solenoids *M* and *M'*. This shunt goes through a 25-watt resistance and relay

3 to the negative source. This circuit, however, is broken by rotation of rotor *RS'*. To sustain the activation of relay 3, the common lead from the upper contact of the keys *K* in addition to going through the closed contact *c* of relay 3 is taken also through relay 2, through the open contacts (but closed by initial activation from *CL'*) of relay 3, through relay 6 and back through the primary of relay 3 to the negative source. As long as a key *K* is kept closed, this circuit is complete. This keeps the contact points of relay 6 open, breaking the escapement circuit, and also the closed contacts of relay 3 open breaking the error circuit.

Since this circuit is closed each time a correct reaction is made, a circuit taken through the contact points of relay 2 and activating an electrical counter *R* will count all correct responses.

A feature of the general apparatus not yet mentioned is that by changing the proper leads (those from *K* to *RS* and from K^x to *RS'*) any particular key can be made to correspond to any one of the stimuli. These leads can be changed in an average time of one minute. The particular correspondence between keys and stimuli used for any performance may be termed the code for that performance.

The apparatus is constant in the speed with which it makes the changes in stimuli. The amount of movement involved in making any 23 successive changes is the same. (This is true only of 23 changes or a multiple of 23.) The time required to make 23 changes should therefore be used as the unit in measuring the constancy of the apparatus. 2300 readings of the time taken to make 2300 changes were made from a Dunlap Chronoscope. These readings gave $4.47 \pm .03$ seconds as the time for 23 changes.

The apparatus as described has been used for more than 100 hours actual running time. It proved quite dependable and shows little wear except on escapement pins *EP* and *EP'* which are of cold rolled steel. They should be replaced with hard steel pins.

If one desires to use auditory or other forms of stimuli, the electrical controls for these can be had by inserting relays

or connecting directly in series with the markers 1, 2, 3, 4, and 5 (Plate 3). In fact if color stimuli were to be used again by the writer, the 75-watt resistance lamps (shown next to the markers in Plate 3) would be used as the light sources and the light from each passed through its own filter. This would obviate the use of the rotating color disc and the shutter.

References

1. Morgan. The Overcoming of Distraction and Other Resistances. *Archiv. of Psychol.*, 1916, No. 35, 1–84.
2. McComas. Apparatus for Recording Continuous Discrimination Reactions. J. of Exp. Psychol., 1917, *2*, 171 ff.
3. Pressey. The Influence of Color upon Mental and Motor Efficiency. *Amer. J. of Psychol.*, 1921, *32*, 326–356.
4. Bair. The Practice Curve. Psychol. Rev. Monog. Suppl., Vol. 5, No. 19, 1902.
5. Coover and Angell. General Practice Effect of Special Exercise. *Amer. J. of Psychol.*, 1907, *18*, 328 ff.
6. Hansen. Serial Action as a Basic Measure of Motor Ability. Psychol. Monog., 1922, *31*, 320–382.

PLATE I

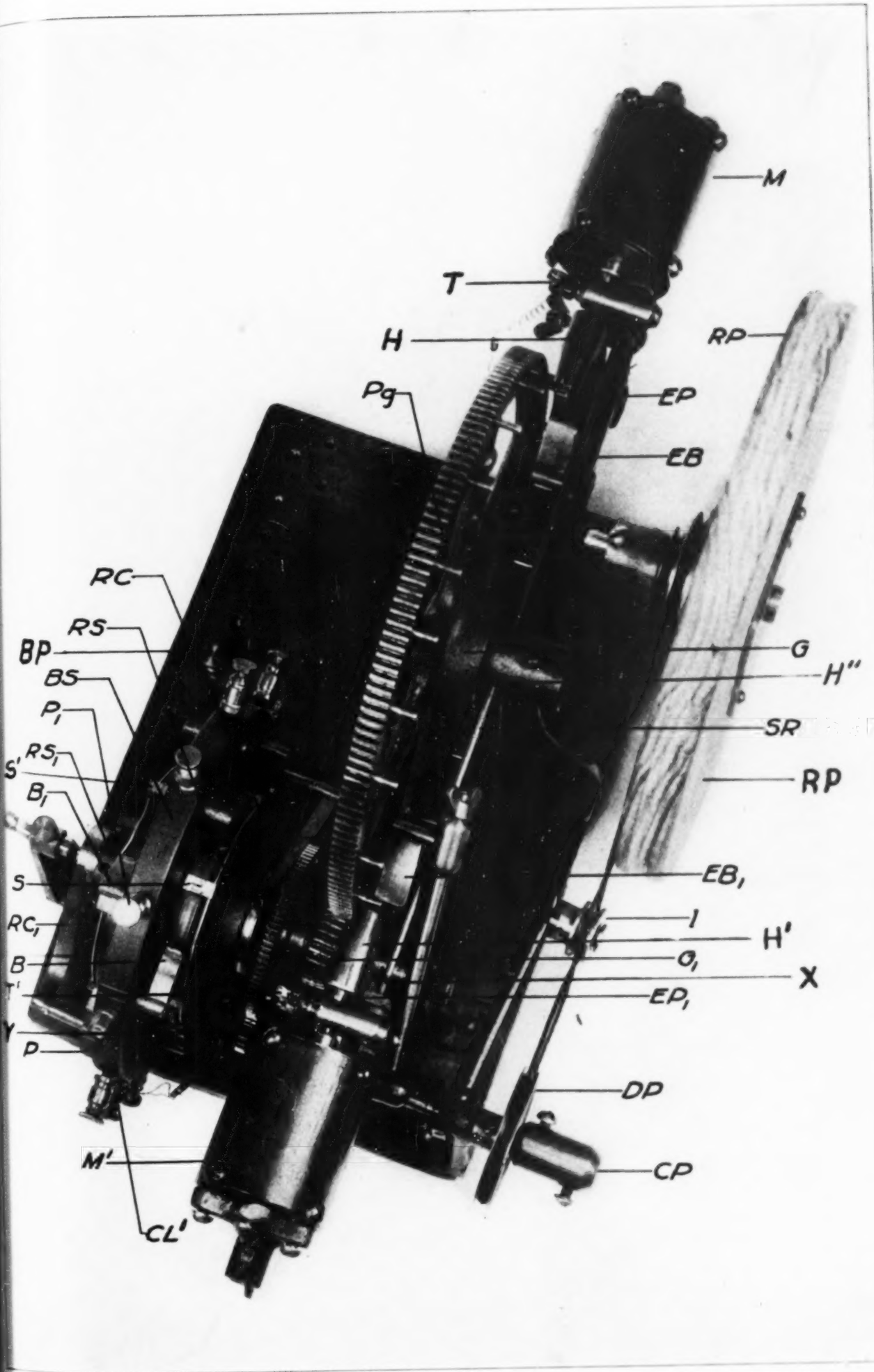
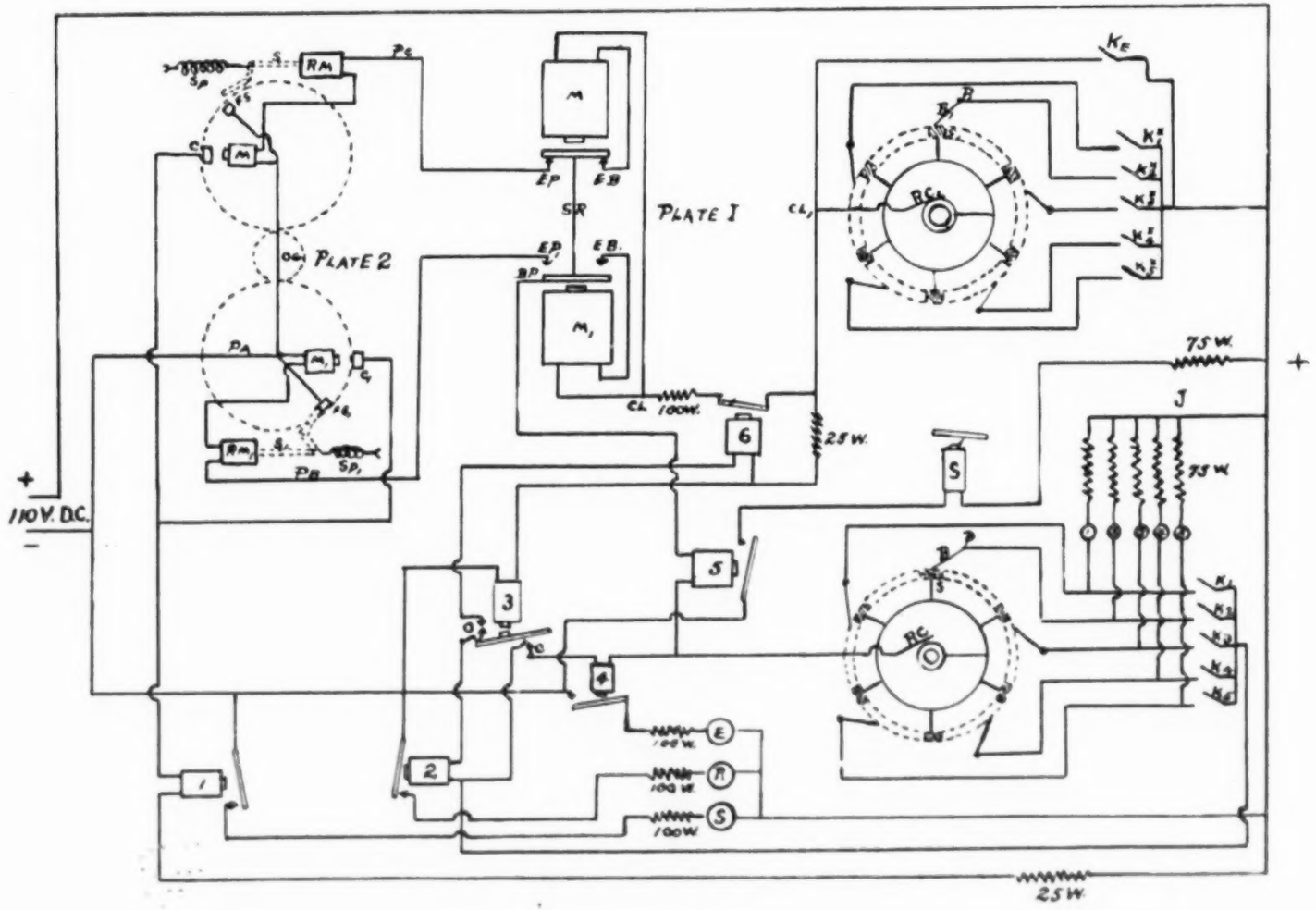

M
T
H
RP
Pg
EP
EB
RC
RS
BP
BS
P1
RS1
S'
B1
S
RC1
B
T'
Y
P
M'
CL'
G
H''
SR
RP
EB1
1
H'
O1
X
EP1
DP
CP

PLATE III

PLATE III


110 V. D.C.
+
−
PLATE 1
PLATE 2
RM
M
EP
EB
SR
BP
M1
PA
PB
SP1
CL
100W.
25 W.
75 W.
J
KE
BCA
BC
1
2
3
4
5
6
S
E
R
S
100 W.
25 W.

CLASS RESULTS WITH SPACED AND UNSPACED MEMORIZING

BY KATE GORDON

University of California, Southern Branch, Los Angeles

Desiring to illustrate, for large classes in psychology, the principles of spaced and unspaced memorizing, I chose the Athenian Oath as the material to be learned.

THE ATHENIAN OATH

I will never disgrace these sacred arms, nor desert my companion in the ranks I will fight for temples and public property, both alone and with many. I will transmit my fatherland, not only not less, but greater and better than it was transmitted to me. I will obey the magistrates who may at any time be in power. I will observe both the existing laws and those which the people may unanimously hereafter make, and, if any person seek to annul the laws or to set them at nought, I will do my best to prevent him, and will defend them both alone and with many. I will honor the religion of my fathers.

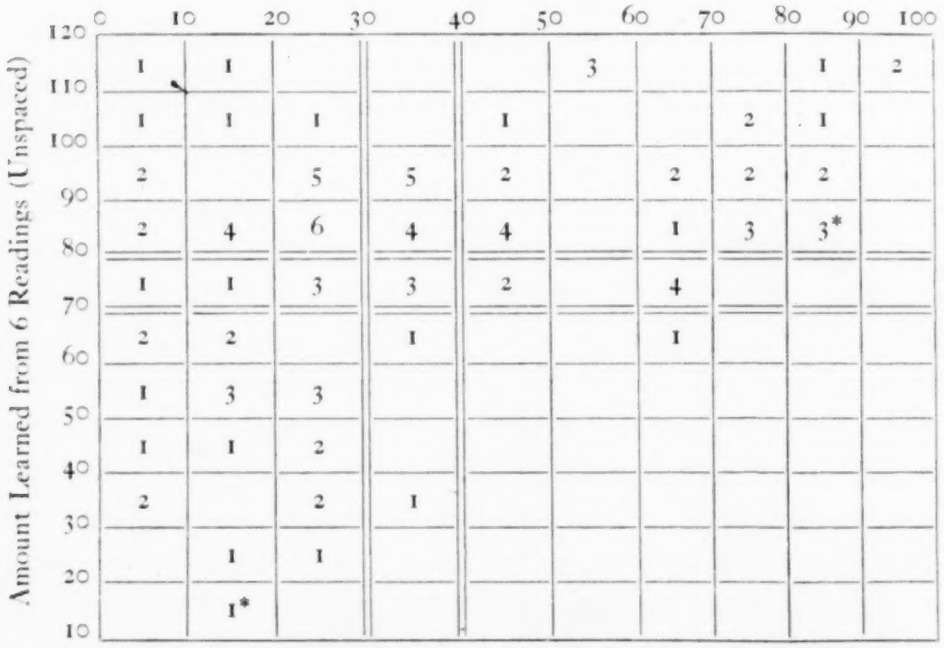
Meaningful material was selected, in preference to nonsense material, for two reasons. The first reason depends upon the fact that the presentation had to be auditory, a controlled visual presentation not being feasible in lecture rooms where many of the students have to be seated in unfavorable locations. When auditory series are to be apprehended, meaningful material has better carrying power than nonsense material. The student listening to nonsense syllables, even though they be loudly and clearly spoken, is apt to think that he may not have heard correctly. In the second place, a better spirit of coöperation is secured with elementary students when the selection to be learned has some intrinsic worth. Students are fairly willing to learn that which has some beauty or dignity—if not too long!

The program of the experiment was as follows: To four college classes in psychology, designated as Class 1, Class 2, Class 3, and Class 4, the Athenian Oath was read aloud according to four different plans.

To Class 1 (numbering 101 persons) I read the selection through 6 times in succession, allowing about one half minute between readings. The students were instructed to listen attentively, with a view to retaining what they heard, but to take no notes. At the end of the sixth reading they were asked to write down all that they could recall and to hand in their papers. They were then told to think no more about the experiment, to take no notes on it, and to refrain from discussion of it until further notice. They were explicitly assured that their recollection of the selection could make no difference at all in their scholastic grades. Four weeks later, without any additional reading of the piece, the class was required to write down what they could then recall.

MATERIAL MEMORIZED BY UNSPACED METHOD

Retained after 4 weeks



$N = 101$ Mean $y = 80$, S.E. $= 2.2$ Mean $x = 37$, S.E. $= 2.5$ $r = +.42$

FIG. 1

The papers were scored by giving one point credit for each word correctly reproduced. For a word put in the wrong place, a penalty of one half point was deducted from the total score. The whole selection contains 115 words,

therefore 115 is the maximum score. All the papers were scored by one person, Miss Carol Taggart, to whom I am indebted for this labor.

Figure 1 shows the results of Class 1. Along the ordinates are distributed the scores which were made in the first recall, immediately after the 6 consecutive readings. Along the abscissas are distributed the scores made in the second (delayed) reproduction, after the interval of 4 weeks. The average score for the immediate recall was 80 points. The average score for the delayed recall was 37 points. Hence, by the end of a month, slightly more than a half of what had been learned was forgotten.

It is interesting to observe the correlation between the immediate and the delayed reproductions, because it gives us further evidence on the principle that the ready learners are the long retainers. The coefficient of correlation is + .42, indicating a positive, though not exceptionally high correspondence between rapid learning and effective retention. The persons represented in the upper right hand quadrant are those who learned quickly and retained well. But there is, in the upper left hand quadrant, a number, almost as large, who learned quickly and retained poorly. In the lower left hand quadrant are those who learned little and retained somewhat less, although in this group there are some who retain a larger percentage of their first achievement than do some of the ready learners. The persons represented in the lower right hand quadrant (in this table only one) are those who were below the middle range in their first scores, but above the middle range in their second scores. It is hardly to be expected that this quadrant would have a numerous population; for, in order to have the entries spread far out to the right, it would be necessary for the subjects to recall more, after a month's delay, than they were able to recall immediately after hearing the selection. This is contrary to general expectation, although it is known to happen in the phenomenon of 'reminiscence,' so well described in Ballard's important study. The instances of reminiscence noted in the present study will be mentioned below.

To Class 2 (numbering 74 persons) I read the Oath 3 times in immediate succession on one day, not allowing any reproduction at that time. After an interval of 3 days, I read it 3 more times in succession. At the end of this sixth reading the subjects wrote out their recollections and the papers were collected. After an interval of 4 weeks a second reproduction was requested. Thus the procedure was the same as for Class 1, except for the space of 3 days which intervened between the third and fourth readings. Fig. 2

Fig. 2

shows the results for Class 2. The average score of Class 2 for the first recall was 76 points, and their average score for the second recall, 4 weeks later, was 48 points. Their attainment on the first recall was slightly less than that of Class 1, *i.e.*, 76 points as against 80. But their second recall was appreciably better than that of Class 1, being 48 as against 37. In this instance, therefore, the spaced method of learning appears to be slightly inferior for immediate recall,

but definitely superior for later recall. The correlation between first and second recall is notably higher in the case of spaced learning, being + .70 as in Fig. 2. Comparisons between Class 1 and Class 2 are summarized below in Table I., in which the four classes are brought together.

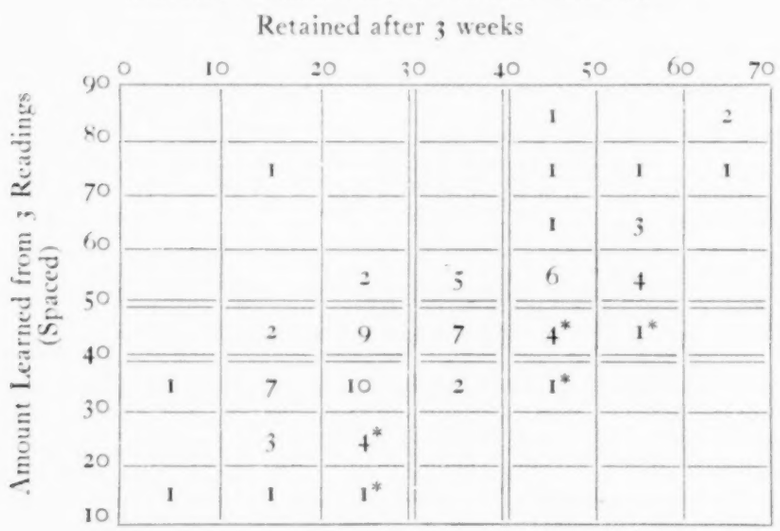
Class 3 (numbering 40 persons) heard the Oath read 3 times in succession on the same day and immediately reproduced it. Then followed an interval of 3 weeks, at the close of which a second reproduction was requested. The results of this group are given in Fig. 3. Here the average score was 54 points for immediate recall, and 26 points for the delayed recall. The correlation between the first and second reproductions is + .52.

Material Memorzed by Unspaced Method
Retained after 3 weeks
Amount Learned from 3 Readings (Unspaced)
0 10 20 30 40 50 60 70
100 90 80 70 60 50 40 30 20 10 0
N = 40 Mean y = 54, S.E. = 3.6 Mean x = 26, S.E. = 2.1
r = + .52

Fig. 3

Class 4 (numbering 82 persons) also heard the Oath read 3 times, but there was an interval of a week between the first and second readings, and another week between the second and third readings. Immediately after their third reading a reproduction was called for, and after a further interval of 3 weeks a second reproduction was requested. This procedure was the same as for Class 3 except for the spacing of the

readings. Fig. 4 exhibits the achievements of Class 4. Their average score was 45 points for the first recall, and 32 points for the second recall. As compared with Class 3 they are somewhat inferior on immediate recall, but slightly superior on delayed recall. The correlation between first and second recall for Class 4 (spaced learners) is + .71.


Material Memorized by Spaced Method
Retained after 3 weeks
Amount Learned from 3 Readings (Spaced)
0 10 20 30 40 50 60 70
90 80 70 60 50 40 30 20 10
1 2
1 1 1
1 3
2 5 6 4
2 9 7 4* 1*
1 7 10 2 1*
3 4*
1 1 1*

$N = 82$ Mean $y = 45$, S.E. $= 1.7$ Mean $x = 32$, S.E. $= 1.6$
$r = + .71$

Fig. 4

A summary of the average scores for the four classes is presented in Table I.

Table I

	Number of Readings	Type of Drill	Average Score on Recall		Correlation between Imm. and Del.
			Immediate	Delayed	
Class 1.....	6	Unspaced	80	37	.42
Class 2.....	6	Spaced	76	48	.70
Class 3.....	3	Unspaced	54	26	.52
Class 4.....	3	Spaced	45	32	.71

The instances of reminiscence will now be mentioned. I use this word in Ballard's sense, to indicate the cases in which a subject makes a higher score on his delayed reproduction than on his immediate reproduction of material. There were eleven such cases found out of the total of 297 persons

with whom this study deals. The locations of these cases are shown by the asterisks in the four figures printed above. For example, in Fig. 1 there is one case in the column 80–90 where it intersects the row 80–90, and another in the column 10–20 where it intersects the row 10–20. The differences in score were not large enough to exceed the class interval. The largest improvement was made from a score of 42 to a score of 55, *i.e.*, a step of 13 points. The average improvement for the 11 cases was 4.6 points. It must be said that in groups as large as those dealt with, it might be possible for students to get assistance from a neighbor without being detected, but I found no reason at all to suspect such a thing, and the instructions made it clear that there was no advantage to the student in such a course. The low scores in the group under consideration also speak for their honesty. The unusual score secured by one student, *i.e.*, one who made 114 points on the first recall and 115 on the second, was attained by an exceptionally bright girl who had already proved her good verbal memory before this experiment.

Inspection of the several cases of reminiscence reveals the fact that in 9 instances the first score was below the average of the group and in 2 it was above, and that in 6 instances the second score was below average, and in 5 above average. On the whole, therefore, the phenomenon was characteristic of the poor memorizers rather than of the good ones.

Summary

1. Concentrated readings of the material learned proved slightly more advantageous in immediate recall.

2. Spaced readings proved more advantageous in a second, delayed recall.

3. When learning had taken place by the spaced method there was a closer correlation between immediate and delayed recall than in case of unspaced learning. The coefficients for spaced learning were + .70 and + .71, and the coefficients for unspaced learning were + .42 and + .52.

4. Reminiscence occurred in approximately 4 per cent. of the persons tested, and was more frequent among the poorer memorizers.

PHOTOGRAPHIC RECORDING OF EYE MOVEMENTS IN THE READING OF CHINESE IN VERTICAL AND HORIZONTAL AXES: METHOD AND PRELIMINARY RESULTS

BY W. R. MILES AND EUGENE SHEN

Department of Psychology, Stanford University

The observation of eye movements by means of photographic recording for the purpose of studying the reading process has already been extensively made in the case of the English language.[1] Many such studies have been carried out at the University of Chicago, and published in the *Supplementary Educational Monographs*.[2] From personal sources, we recently learned that Dr. Shigeru Otomo in a study, also made at Chicago, used Japanese texts. His results are not yet available to the public. The present paper will present the method and some results of our first attempts, made at Stanford University, at photographing eye movements in the reading of Chinese.

The experiment is especially interesting because Chinese is radically different from most other languages that have been studied in this manner. It is not based upon phonetic spelling. All characters are essentially perfect squares, though each may contain from one to more than thirty strokes. The simplest form is a horizontal line, while other characters sometimes look disconcertingly complicated. A-

[1] Raymond Dodge, 'The Psychology of Reading,' *Cyclopedia of Education*, 1917, 5, p. 117.

[2] W. A. Schmidt, 'An Experimental Study in the Psychology of Reading,' Suppl. Educ. Mono., 1917, *1*, Whole No. 2, pp. iv + 125, Uni. Chicago Press. C. T. Gray, 'Types of Reading Ability as Exhibited Through Tests and Laboratory Experiments,' *ibid.*, 1917, *1*, Whole No. 5, pp. xi + 196. These studies, now unfortunately out of print, were the first of this important series of investigations to come from the School of Education at Chicago. For illustrations showing their elaborate equipment for photographing simultaneously the movements of both eyes see: A. R. Gilliland, 'Photographic Method for Studying Reading,' *Visual Education*, 1921, *2*, p. 21.

side from the vocabulary, the style has a wide range of difficulty. While traditionally the characters have always been arranged in vertical columns, a large number of recent Chinese publications have adopted the horizontal axis for alignment. The punctuation marks also vary in elaboration, from their entire absence through uniform dots or circles to a system more complicated than that used in English. The photographing of the eye movements thus affords an excellent means of studying various problems arising from such differences.

METHOD

A general view of the apparatus is shown in Figure 1, *A*.[1] It will be recognized as a compact form of the Dodge type [2] of equipment mounted as a complete unit on one table which is secured to the floor in a manner calculated to avoid vibration. The adjustments to be made are simple and direct and offer such ranges of possibility that the apparatus may readily serve for photographing eye movements under a considerable variety of conditions. The subject is seated at a firm headrest; one eye is illuminated from a point-source type of lamp with the use of small mirrors; the lens of the enlarging camera is directly in front of the eye to be photographed and the film at the other end may be continuously moved horizontally or vertically as required.

The source of light was a carbon arc lamp (*L*). A time wheel (*M*) operated by a synchronous motor (*N*), the tuning fork control of which is not visible in Fig. 1, was turned at the rate of 5 revolutions per second.[3] Openings in this

[1] Nearly all of this equipment was very generously given to Stanford University, Dept. of Psychology, by the Carnegie Institution of Washington, Washington, D. C., in 1922. It had formerly been in use at the Nutrition Laboratory, Boston, Massachusetts.

Dr. Francis G. Benedict, Director of Nutrition Laboratory, most kindly suggested the transfer of this apparatus to Stanford University.

The arc lamp and the film camera were made possible by the Thomas Welton Stanford Fund for Psychological Research.

[2] Raymond Dodge, 'An Experimental Study of Visual Fixation,' Psychol. Rev. Monog. Suppl., 1907, *8*, Whole No. 35. Pp. iv + 95. See Plate III. *Cf.* also Dodge and Cline, 'The Angle Velocity of Eye Movements,' *Psychol. Rev.*, 1901, *8*, p. 145.

[3] This time marker was devised by M. Bull of the Marey Institute, Boulogne-sur-Seine, for use in electro-cardiography. Made by Pirard and Cœurdevache, Paris.

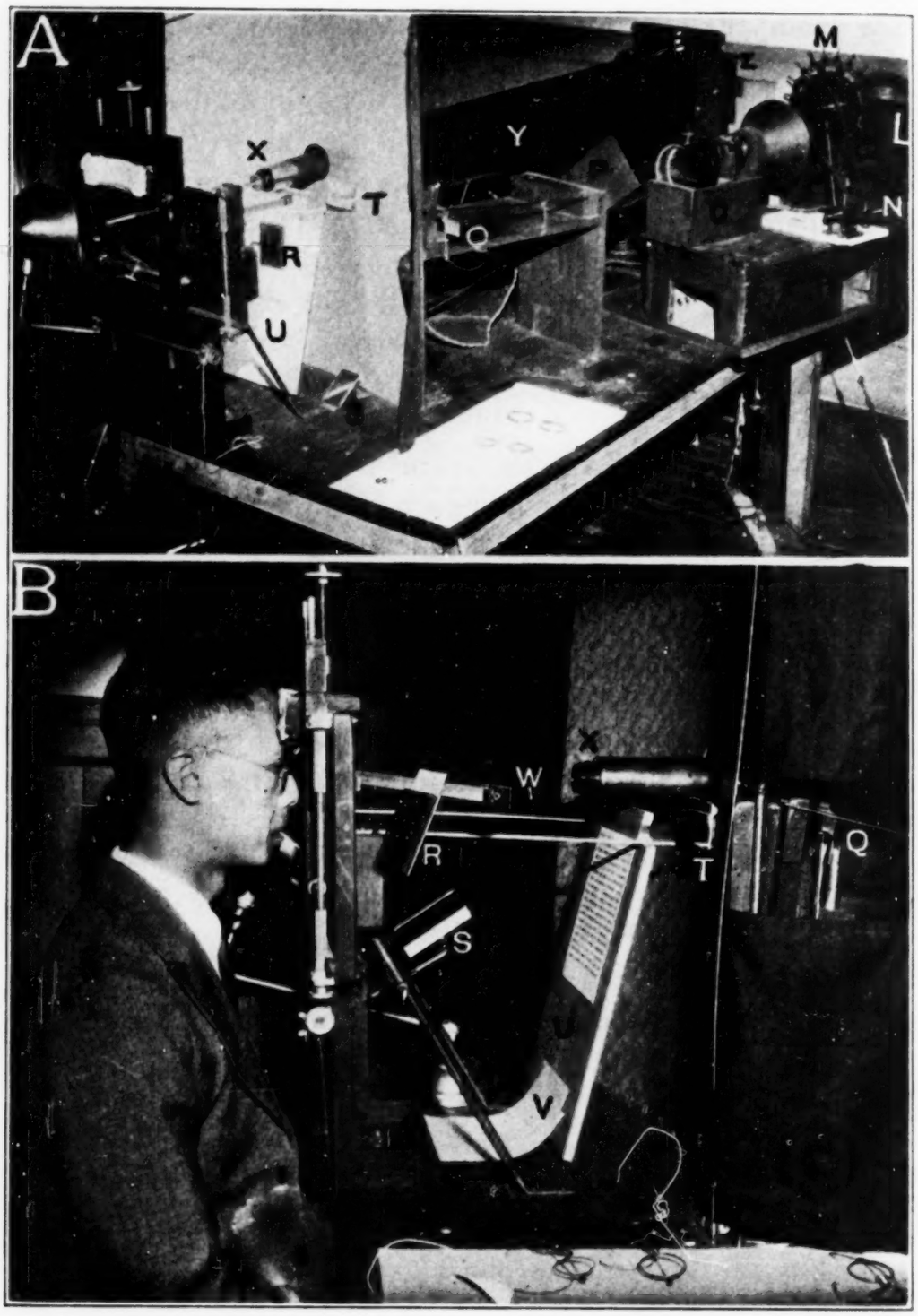


FIG. 1. Equipment for photographing eye movements during reading.

(*A*) General view showing compact arrangement of the apparatus mounted as a unit on one table, which is securely braced to the floor.

(*B*) Subject in position for having eye movements photographed during reading. The mirrors, *R* and *S*, for conducting the recording light to his eye were at the subject's right and did not obstruct his binocular view of the copy. See text for description of lettered parts.

wheel interrupted the light at its focal point so that the photographs obtained were series of dots, each having a certain time value. The unit of time recorded was variable according to the number of openings in the wheel, *i.e.*, according to the position of the wheel in the beam of light, as the wheel has concentric rows of openings varying in number. For our purpose it was found most expedient to use the fiftieth-seconds, with one opening filled in so as to produce a prominent break in the line of dots at every fifth of a second to facilitate reading of the records. The light passed through a double projection lens, so placed that it was directed into a parallel beam. A blue glass-plate and a cooling cell (*O*) were intercepted to reduce the intensity of the light. All the marginal light was cut off by the use of a diaphragm (*P*) 1 cm. in diameter. This served the important purpose also of reducing the size of the reflected image on the cornea so that the photographic record was a finer line and the time dots were more clearly distinguishable than when the full aperture of the projection lens was exposed. A control shield (*Q*) was set beyond the diaphragm so that the light might be entirely shut off from the subject's eyes when desired. It was operated by cords attached to the back end of the camera near where the experimenter sat. Both the arc light and the time wheel were also within his reach for adjustment.

Two small first surface mirrors near the subject were for the purpose of reflecting the light upon his right eye. In the close-up view of the front end of the apparatus (Fig. 1, *B*), which shows a subject in position, the relation of the mirrors may be made out. The light from the lantern was received by *R*, reflected to *S*, or to *T* as conditions required, and from this latter mirror to the eye. The entire eye is, of course, illuminated. However, the feature that is of prime importance for photographic records of eye movement by the Dodge method is the sharp high-light that, due to the curvature, is reflected from the cornea. It is this small bright spot that is focused upon in photographing. It is desirable that the position of mirror *S*, be such that the light can only be seen

in indirect vision when the subject is reading and also that the high-light shall be reflected from the central portion of the cornea. Provision must also be made that the light shall come to the eye from such an angle that movements of the upper lid, which are associated with directing the line of regard downward, shall not obstruct it.

The reading material was placed on an inclined copy holder (*U*) below the lens (*X*) of the camera. The distance from the subject was easily adjustable as can be seen. A screen (*V*) was held over the copy by means of a rubber band. The latter was attached to a cord (*W*) which the experimenter could pull, without movement of the copy holder, and with no change in the lighting, thus quietly dropping the screen and exposing the text after the subject had fixated certain dots that represented the total length of the printed line. An ordinary reading lamp placed at the left of the headrest, gave satisfactory illumination to the reading matter. The reading was done with binocular vision, although only movement of the right eye was recorded. To register any possible head movement, a spectacle frame carrying a metal bead was worn, as shown in *B* of Fig. 1. The head and tooth rest, which were adjustable, as was also the height of the chair, made it possible for the subject to be comfortable and at the same time to hold the head still, during reading. The subject had a wide and unobstructed view and the arrangements were such that a relatively large sheet of copy (6¼ inches square of text) could be read in one continuous record. The advantages of using these full pages of copy for securing natural reading performance are obvious.

The barrel, or hood of the enlarging camera (*Y*) including the tube which carried the lens and projected into the foreground, was about 66 inches long. A Bausch and Lomb Protar lens was used. The magnification in this study was five times. Other magnifications up to nine times may be obtained with this equipment. The lens end of the camera could be raised or lowered and the whole camera, as it rested on a firm table top, was capable of any adjustment in the horizontal plane.

The most difficult feature to arrange in such a photographic outfit is doubtless the film moving unit. It is desirable to move the film continuously with even speed at any one of several different rates and in horizontal as well as vertical axes. We discovered a commercial form of pano-

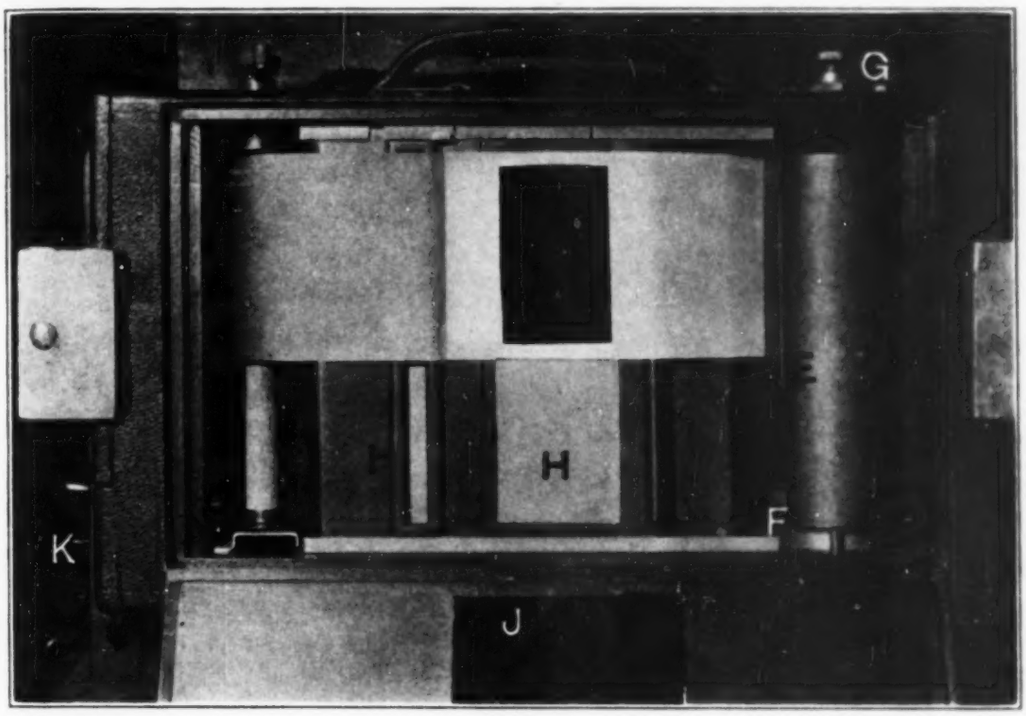


FIG. 2. Film box of panoramic type with back opened as when focusing for recording eye movements. The film is given a continuous even movement by being rolled upon drum *E*, which is revolved by spring motor, *F*, when the drum is clamped to the motor by nut, *G*. The focusing glass, *H*, may be moved behind the opening cut in the paper attached to the first end of the film. The box is easily clamped in any axes along which it is desired to move the film.

ramic camera which almost without any modification meets these needs admirably. This camera [1] is so useful as a photo-kymogrgph either by itself or in combination with other photographic equipment that it warrants brief description. The essential nature of the device may be readily understood from Fig. 2, which shows it attached to the hood (*Y* of Fig. 1) in one of the possible positions and ready for focusing. The rugged, leather-covered box is 12 x 7 x 4 inches, outside measurements. It will carry film 5 inches

[1] Manufactured by Folmer and Schwing Division of Eastman Kodak Co., No. 5 Cirkut Camera. The lens, bellows, and rack and pinion parts were taken off.

wide. The film, or rather the paper leader, is fastened to the drum (*E*), which is 9½ inches in circumference. This drum turns freely until clamped to the shaft of the spring motor (*F*) by a lock-nut (*G*). The spring motor is regulated by a centrifugal friction governor and a train of gears. The rate may be quickly changed by a speed control index near the release lever at *K*. Due to the even rate of the motor and the large diameter of the drum the movement of the film is very regular. The ground glass (*H*) may be slid behind the opening cut in the leader and thus, immediately after focusing and sliding the glass back, the film is ready to be started and reading begun. The recording light is admitted to the film through the opening above *H*, or through the narrower window (*I*). On closing the door the velvet cushion (*J*) holds the film closely against the exposure window. There is a revolution counter for the drum. By releasing the lock (*G*) the film may be rolled back on the spool by means of a small crank. In our investigation we used strips of film 60 inches long by 2½ inches wide. Two or three records could be taken side by side on such a strip.

Illustrative Records

The Dodge method of recording eye movements makes use of the fact that the cornea of the eye, illuminated by a constant beam of light, changes its angle of reflection during movement. The nature of these shifts in the reflected light may be made clear by photographs taken of the whole eye with a stationary negative as shown in Fig. 3. When the eye made a steady fixation during the entire exposure period the cornea reflected a single spot of light as photograph *A* will show. The spot is not perfectly sharp due to very slight eye movements during the attempted steady fixation. The eye made a horizontal movement of 40° during the exposure while *B* and *C* of Fig. 3 were taken, and for *D*, a vertical movement of the same angle. In these three pictures the spectacle frame carrying the metal bead was worn to make possible the recording of the head movement. During the exposure in each case the subject tried to make a steady

fixation at each of the two terminal points and to pass directly from one to the other by one continuous movement, but it can easily be seen that the eye failed to do what the subject thought he did. Photograph *C* best illustrates this interesting feature and was in fact purposely selected from several records. It shows the difficulty, in spite of practice and voluntary effort, of maintaining an absolute fixation for a few seconds. The path of movement apparently is not

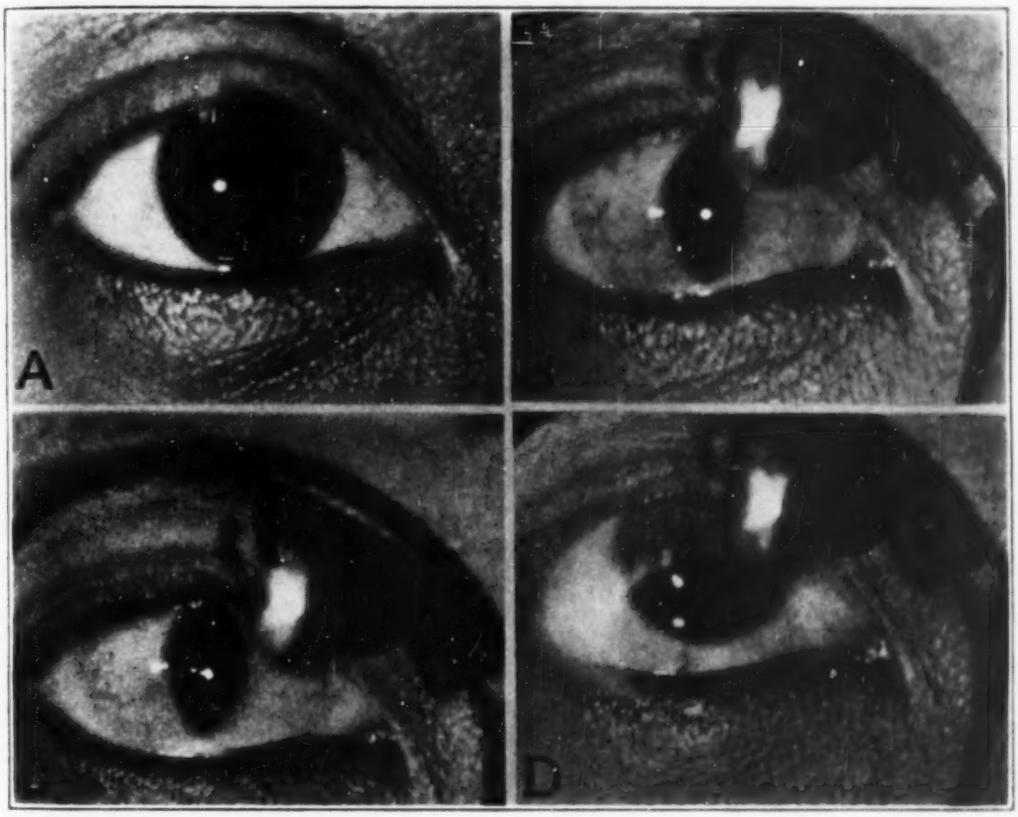
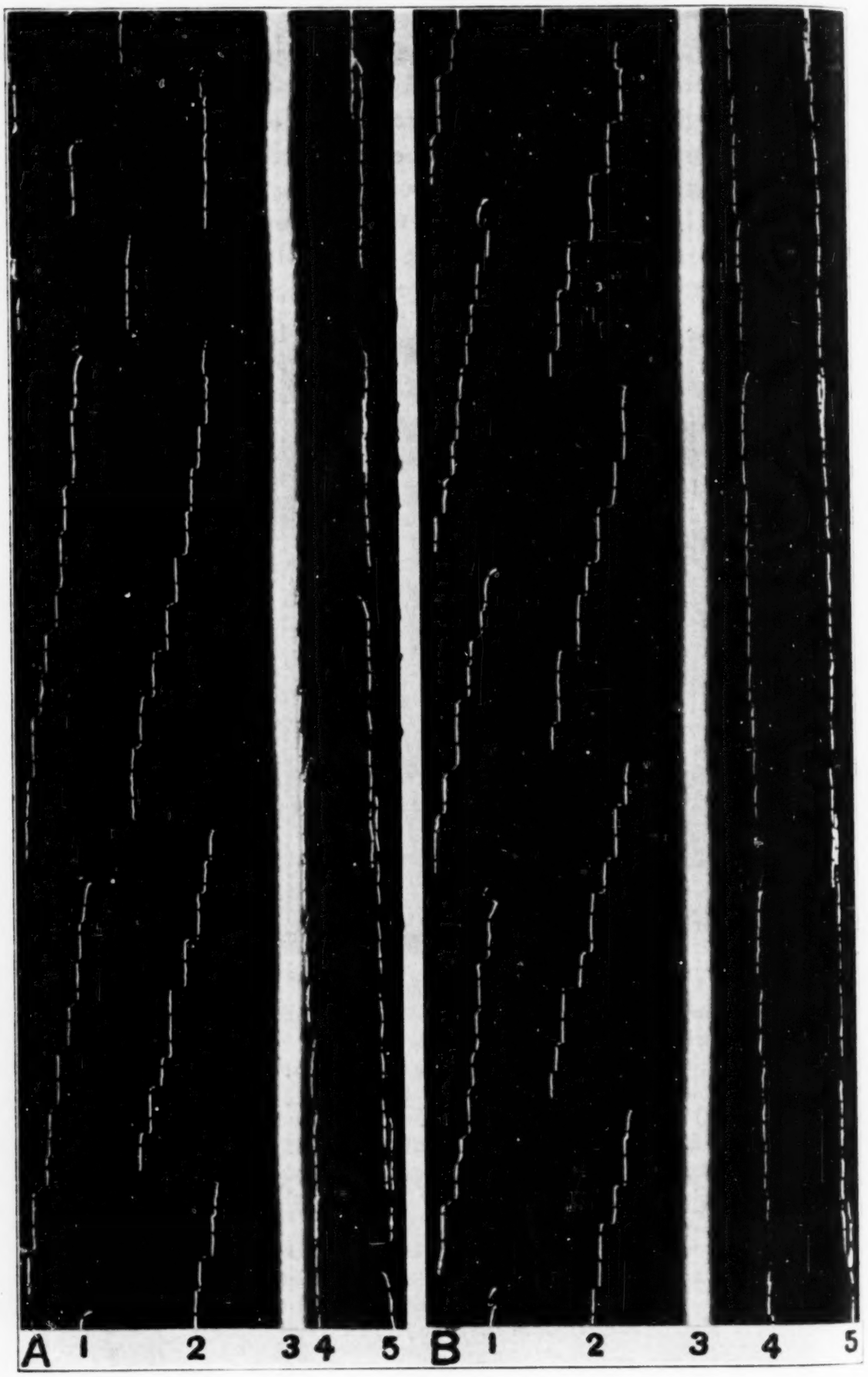


FIG. 3. Photographs (right eye of Chinese subject) with negative stationary, showing the brilliant corneal reflection of a carbon arc and the movements of this reflection associated with eye movements.

(*A*) Fixation practically constant during the entire exposure of the negative, no definite movement of the corneal reflection indicated.

(*B* and *C*) During the first half of the exposure the subject looked at a certain mark, then shifted the gaze to another mark 40° away on the horizontal axis and fixated this second mark during the latter half of the exposure. The approximately horizontal shift of the high-light is clearly indicated and it is noteworthy especially in *C* that the eye stopped at several points.

(*D*) Two fixation points, separated by 40° in the vertical were viewed. First the upper one and then the lower mark. In lowering the line of regard the movement was slightly nasalward. In *B*, *C*, and *D* the spectacle frame carrying the bright metal bead indicates the method of recording possible head movements.


A 1 2 3 4 5 B 1 2 3 4 5

straight, the horizontal makes a convex curve upward while the vertical slants nasalward as the fixation is lowered. Numerous reading records confirm this tendency for the saccadic movements to fail of executing a straight line between two fixation points.

A sample record of the eye movements in reading Chinese in both vertical and horizontal axes is reproduced in Fig. 4. During the reading the film was moved continuously by the spring motor mechanism (Fig. 2) described above. Four different reading trials are represented. In some the film was moved perpendicular to the line of type, *i.e.*, to the plane of eye movement, while in the others the film ran parallel and in the same direction as the print.

In the former, see records 1 and 2 (*B* is a continuation of *A*), each large displacement after the preliminary fixation at

FIG. 4. Illustrative records of the eye movements in reading Chinese in both vertical and horizontal axes. The length of line (6¼ inches) and the number and size of characters were the same and the difficulty of reading material approximately the same for both alignments. Photographs reproduced full size. The two sections are parts of the same record, *B* is a continuation of *A*. Both should be interpreted from the top downward. Four different reading performances are represented. Record 1 is vertical reading with the film moved horizontally; the headline (3, light from metal bead on spectacle frame) belongs with this record.

Record 2 is for horizontal reading with the film moved in the vertical.

Record 4 represents vertical reading with the film moved downward in the vertical.

Record 5 is for horizontal reading when the film was moved from the subject's left to right.

At the top of *A*, 1 and 2, the movements represent successive fixations of dots placed one at each end of the first line of copy. The screen (*V*, in Fig. 1) while covering the reading material and before it was dropped left these dots exposed. The fixation of these dots makes it possible to compare these movements with the shifts which occur between successive lines in reading. Characteristic differences are shown between the preliminary fixations for vertical and horizontal axes. The latter seems to be rather less complicated, with movements more direct and also more rapid. The amplitude for the horizontal axis is greater by about 3 mm. the values being approximately 8 and 11 mm. This difference modifies somewhat the appearance of the two reading records. The time is recorded in fiftieths of a second. Every one fifth second one dot of light is dropped out. Therefore the records show 9 closely joined dots of light between breaks. Shifting vision from the end of one line to the beginning of the next, in this case a distance of 6¼ inches, requires about .05 of a second. The individual pause of the eye on some character during reading occupies more nearly .20 seconds. Records 4 and 5 show that the lateral deviations of the eye away from the direction of the line of reading are relatively small. The two prominent deviations with breaks in record 5 of *A* are winks of the eye.

the very beginning of *A* means a movement to a new line, while the shift from one reading pause to another within the line shows lesser displacements. The relative magnitude of each movement can be seen and the record can be projected upon the reading material by means of a lantern, thus locating the positions of the pauses within the several lines. In the figure it will be noted that eight or nine pauses are used in the reading of each line of copy, whether the arrangement is vertical or horizontal. It should be said that this material was fairly familiar to the man who made this record.

In the records when the film is moved parallel to the reading (4 and 5) forward movement of the eye, *i.e.*, progress within the line is represented by slight breaks and the return sweep to a new line by overlapping, which can be best seen in the case of 5. Records of this sort were taken to examine the shifting of the eye above or below, to the right or the left, of the line of reading material.

Regressive movements are not easily observable in such records, but the duration of the pauses can be determined in both types by counting the dots with the aid of a magnifying glass. The individual time dots do not show well in a reproduced record. By counting the fifth second intervals (gaps in the white line of time dots) the reader may gain a fairly accurate idea of the time values represented.

There are noticeable differences between the records for vertical and horizontal reading. In the latter the pauses seem more steady and distinct, while in vertical reading, they show a tendency to gliding into a continuous curve. This seems to be true aside from the fact that the horizontal print records as a somewhat larger lateral deflection in our photographs. Casual inspection of the records reveals no characteristic difference in the number of pauses, length of pauses, or in the number of regressive movements. There is, however, a distinct difference shown at the time of changing to a new line of print. When reading vertical print, the return sweep of the eye to the beginning of a new line characteristically shows a sharp loop just preceeding the first fixation pause. This feature is commonly found in the records

for all Chinese subjects whom we have used. We have observed it also in records of fixation movements covering 40° in the vertical axis with subjects used to reading only English and European languages in the horizontal.

Results

Two groups of experiments are reported in this paper: (1) a comparison of the eye movements in reading short selections of English and horizontal Chinese of two sizes, with the line length equal, and (2) a comparison of the reading records for Chinese texts of vertical and horizontal alignment. We will present the results for these latter experiments first.

Data were collected from the reading of four selections by each of 11 subjects, all Chinese students at Stanford University. Each selection was a complete paragraph containing 10 to 12 lines, from magazine articles. Selections *A* and *B* were vertical, while *C* and *D* were horizontal. A full vertical column was 6¾ inches in length with 35 characters, and the horizontal line was 5½ inches long with 23 characters. The punctuation system was also slightly different between the vertical and horizontal passages. The characters were of the same size for both alignments. With *B* and *D*, the records were taken while the film moved in the same plane as the eye, in order to detect any lateral shifting in reading a line. The other two were made while the film ran perpendicular to the eye movements, thus recording the spacing of the successive pauses. All four selections were read, in alphabetical order, during one session, preceded by the reading of preliminary material under the same conditions, without actual recording. The subjects were instructed to read silently and understandingly. Speed was left to each subject's own habit and inclination, and comprehension was tested by questions without warning, after all four selections were read.

The average duration in hundredths of a second for the reading pauses of the 11 subjects and for the four selections used are shown in Table I., which gives as well the standard deviation for each average value. The subjects are indicated

by initial letter in the left hand column. Unfortunately there are a few gaps in the table as some of the records were too faint to be read with exactness. In the calculation of the means which are shown in the bottom line of the table, only those subjects having legible records for all four selections have been included. In general it will be observed that the

TABLE I

AVERAGE DURATION OF READING PAUSES, WITH STANDARD DEVIATIONS
(Time units hundredths of a second)

Subject	Selection *A* Vertical	Selection *B* Vertical	Selection *C* Horizontal	Selection *D* Horizontal
P	25 (8.9)	26 (9.3)	23 (8.3)	27 (8.2)
H	43 (16.6)	41 (16.9)	34 (12.8)	36 (13.1)
L	33 (14.1)	35 (14.6)	29 (10.9)	— ——
J	27 (7.5)	— ——	34 (11.8)	— ——
R	34 (10.9)	34 (9.3)	28 (6.1)	32 (9.4)
E	31 (11.1)	32 (11.4)	29 (9.1)	31 (10.9)
W	31 (10.4)	35 (7.9)	33 (12.7)	36 (13.6)
Y	29 (10.4)	34 (14.8)	29 (10.9)	30 (9.3)
K	27 (7.6)	29 (5.7)	— ——	30 (7.0)
T	27 (6.8)	28 (9.3)	— ——	30 (10.2)
C	— ——	29 (11.2)	31 (10.5)	— ——
Mean [1]	32 (11.4)	34 (11.6)	29 (10.0)	32 (10.7)

reading pause for both vertical and horizontal material is about 0.3 seconds. The standard deviation is about ⅓ this value but more variable. The means for selections *A* to *D* in order are .32, .34, .29, and .32 seconds. While, as stated above, *A* and *C* were taken in one manner, that is with the film moving in a direction perpendicular to the line of eye movements and *B* and *D* in another it is not just to compare *A* only with *C* and *B* only with *D* in reference to the duration of the reading pauses. There are really four comparisons to be made: *A–C*, *A–D*, *B–C* and *B–D*. Out of 32 such individual comparisons, 18 are longer for the vertical, 12 longer for the horizontal, and 2 equal.

A more consistent difference for the two alignments as represented by the texts employed, is shown in the average number of words covered by one reading pause. These

[1] In calculation of the means only those subjects having legible records for all four selections have been included.

results are given in Table II., which is arranged in the same manner as the preceding one for the duration of reading pauses. The average number of words perceived, during the time that the eye is quiet in one position in the line, varies from 1.0 to 3.3, but in general is approximately two characters. For the selections *A* and *B* printed in the vertical the mean values for the subjects having legible records are 2.1 and 2.5. The comparable results for selections *C* and *D*

TABLE II

AVERAGE NUMBER OF WORDS PER READING PAUSE

Subject	Selection *A* Vertical	Selection *B* Vertical	Selection *C* Horizontal	Selection *D* Horizontal
P	2.1	2.5	1.6	1.8
H	1.3	1.7	1.0	1.2
L	2.1	1.5	1.4	—
J	2.9	—	2.8	—
R	2.2	2.1	2.3	1.7
E	2.7	3.3	2.1	2.0
W	2.6	3.2	2.8	2.3
Y	2.0	2.1	1.4	1.6
K	2.7	3.2	—	2.2
T	2.7	2.6	—	2.2
C	—	2.0	1.8	—
Mean[1]	2.1	2.5	1.9	1.8

in the horizontal are 1.9 and 1.8 words per pause. To state the results in terms of speed of reading the average number of words per second of time is indicated in the figures of Table III. Here the range is from 2.9 to 11.0. It is observable that the conspicuously high values occur in the columns for vertical selections. The mean values for these selections, *A* and *B* are 6.9 and 7.6 words per second. The results for the horizontal axis are 6.5 and 5.7, for selections *C* and *D* respectively.

Wide individual variations are present, as the tables show and are more prominent than any differences between the texts. In other words, the same subject reads the different selections more uniformly than the different subjects read the same selection. The speed of reading is of course a

[1] In calculation of the means only those subjects having legible records for all four selections have been included.

function of the temporal duration and the spatial span of the pauses. Short duration and long span result in rapid reading, while long duration and short span result in slow reading. Subject *H*, for instance, has the longest pauses as well as the shortest span and consequently reads about half as rapidly as the average and but little more than a third as fast as the most rapid reader.

TABLE III

SPEED OF READING. AVERAGE NUMBER OF WORDS PER SECOND

Subject	Selection *A* Vertical	Selection *B* Vertical	Selection *C* Horizontal	Selection *D* Horizontal
P	8.2	9.4	7.0	6.8
H	2.9	4.2	2.9	3.3
L	6.4	4.3	4.6	—
J	10.7	—	8.2	—
R	6.5	6.3	8.2	5.4
E	8.8	10.6	7.4	6.6
W	8.3	9.0	8.4	6.5
Y	6.9	6.1	5.0	5.3
K	9.9	11.0	—	7.4
T	9.8	9.1	—	7.4
C	—	7.1	5.6	—
Mean [1]	6.9	7.6	6.5	5.7

The number of pauses per line is not tabulated. But from Table II., it can be seen that on the average 14 to 17 pauses are required for a vertical column and 12 to 13 pauses for a horizontal line. As the latter has a length equivalent to only 81 per cent. of the former, the apparent great difference need cause no wonder.

A general comparison between vertical and horizontal reading in the three tables shows that the vertical has a slightly longer duration of the reading pauses but each pause covers a greater number of words. The resultant of these considered in terms of number of words read per second, therefore, seems to give the vertical some advantage. It must be said however that no unequivocal conclusion for comparing vertical with horizontal could be stated on the basis of these experiments, since comparisons in regard to length of line, leading, and punctuation as well as content

[1] In calculation of the means only those subjects having legible records for all four selections have been included.

are not warrantable. However, further experiments made with strictly comparable texts for the two alignments although not yet ready for publication bear out these results.

Our data on different sizes of Chinese and on English were gathered during the preliminary stages of our study under conditions slightly different from those described above. Instead of the moving film, we used a Dodge falling plate camera.[1] Chinese was used only in the horizontal form, and each piece of reading material was limited to not more than four lines. These were exposed by means of a tachistoscope placed to the left of the lens at an adjustable distance from the subject. The reflecting mirror *S* was farther to the left than the position shown in Fig. 1, *B*. We employed the two sizes of Chinese characters, No. 4, about 3/16 in. sq., 23 characters to the line; and No. 5, about 2/16 in. sq., in lines of 30 characters. Also we used two sizes of English, 9-point modern style, which has an average of 14–15 words to a line, and 12-point old style, 13 words to a line.

The length of line was practically equal, being 5½ inches except for the 9-point English, which was 5 inches. The English and Chinese texts were the ordinary sizes of magazine print and seemed to us comparable in legibility. The large size Chinese was exposed three lines at a time, all others four lines. Only the writers served as subjects, but no less than 75 records were made in all. Thus the average values given in Table IV. are representative of the subjects. Although

TABLE IV

COMPARISON OF THE READING OF CHINESE AND ENGLISH AND OF DIFFERENT SIZES OF TYPES

Subject	Language	Size	Pauses per Line	Time per Pause (Seconds)	Words per Pause	Words per Sec.
M.....	English	9-pt.	10.5	.30	1.4	4.7
M.....	"	12-pt.	9.9	.33	1.3	3.9
S.....	"	12-pt.	11.9	.32	1.1	3.4
S.....	Chinese	No. 4	13.7	.24	1.7	7.1
S.....	"	No. 5	16.4	.27	1.8	6.7

[1] See note 1, on p. 345.

these results may not be typical of the general reader, a comparison between the type sizes and the two languages is justifiable.

From Table IV., it is seen that in Chinese as well as in English the smaller size (9 pt. English and No. 5 Chinese) requires a greater number of pauses per line, but each pause covers a slightly greater number of words. The duration per pause is slightly shorter for small-size English and large-size Chinese, than for large-size English and small-size Chinese, respectively. The results in terms of words per second reflect the fact that the difference between the two sizes of Chinese was not so marked as between those of English.

The more interesting comparison is between Chinese and English. It appears rather definitely that the reading pause in the case of Chinese is shorter than in English, both spatially and temporally. This twofold difference influences the speed of reading in two opposite directions. But the number of words read per pause is much greater for Chinese, which has more words to a line. If, therefore, the number of words read per unit time is taken as the criterion for reading speed, Chinese is apparently read more rapidly than English. It should be mentioned that English is to S a foreign language, but the general tendency holds no less well if we only use the record of M for English.

Discussion

In general, we may say that the process of reading Chinese is essentially the same as for reading English. Each line is covered by a series of pauses and movements, and by each pause usually more than one character is read. Differences between Chinese and English in the number of pauses per line, of words per pause, and of words per second are attributable to the fact that Chinese words are all squares and are more compact than the English words. The space for an English word of average length can more than accommodate one Chinese character that is of equal visibility; hence the difference in the number of words per pause. On the other hand, one fixation placed at a significant part may be adequate

for reading a long English word, while several Chinese words occupying the same space may not be all clearly perceptible at once; hence the difference in the number of pauses per line. The difference in the duration of the reading pause we shall not attempt to explain, since a comparison between Tables I. and IV. indicates that S had a shorter duration of pauses for Chinese than the average of the group of subjects, and that the latter is rather similar to the pause duration for English.

The square shape of the Chinese characters makes the accurate location of a reading pause, from the photographed record, relatively more difficult. Shifting seems to often occur within a pause, rendering it occasionally impossible to locate the pause upon a single character. A slight amount of lateral shifting is also present, suggesting that either the eye movements lack perfect coördination or some part of a character attracts attention more than the other parts. In extremely slow reading, movements are sometimes so short that accurate separation into pauses becomes very difficult.

Regressive movements occur rather often and are to be explained differently on different occasions. The most frequent cases are undoubtedly due to inadequate perception, when the eye leaps too great a distance or leaves a fixation too soon. When the movement is long, faulty attention is probably involved, or it may be due to misinterpretation which is not discovered until revealed by subsequent reading. Several cases are found where a regressive movement sweeps back to the end of the preceding line after landing at the beginning of a new one. Here, besides the explanations already suggested, landing at a wrong line may be responsible. Regressive movements at the beginning of a line, which are more frequent than elsewhere, mean that the return sweep often stops short of the requisite distance. This error of doing too little rather than enough or too much is confirmed by measurements of simple saccadic eye movements. It appears to be a tendency to abbreviate the coördination.

That vertical and horizontal eye movements are qualitatively different has already been mentioned in connection with the illustrative records. The making of a loop in the

upward return sweep is a rather common occurrence. We are not entirely satisfied with any explanation of this curious phenomenon, although it may be attributable to the generally accepted assumption that vertical eye movements involve a more complicated coördination of the muscles than do horizontal movements. Photographic records of vertical and horizontal reading where the length of line is identical show a greater displacement of the terminal points in the horizontal. This is also a feature for which we shall not here attempt any definite explanation.

Naïve speculation upon grounds of the position and opening of the eyes, of the external muscles involved in movement, of the movement of the eye-lids, and of the usual over-estimation of vertical distance would lead one to expect horizontal reading to be the more efficient. But our results do not bear this out. While the data presented in this paper warrant no hard and fast conclusion for lack of strictly comparable reading material, it may be stated that vertical reading seems also to be at an advantage in a more elaborate study, now near completion. This other study made use of duplicate forms of six kinds of material with varying degrees of difficulty, each form being especially printed in the two axes, with equal length of line and equal spacing of the characters. As the horizontal method of reading is of comparatively recent origin as an alignment for Chinese texts, our subjects have undoubtedly had more experience in vertical reading. It is conceivable that long continued practice *may* have more than balanced any inefficiency for the vertical axis, but nothing yet has come to light to show that vertical reading is intrinsically less efficient than horizontal.

ON THE EFFECTS OF THE LOSS OF SLEEP

BY THOMAS FISTER WEISKOTTEN, M.A.

University of Michigan

Experiments dealing with the effects of fatigue have been very common in the field of experimentation, and yet, as one searches the literature on this subject, he is impressed with the very small number which have to do with the effects of fatigue induced by the loss of sleep. A more thorough knowledge of these effects, based upon scientific investigation from a larger number of studies, is greatly needed in this present day, and we feel that no apology is necessary in offering these findings on the effects of fatigue induced by the loss of sleep.

The first experiment of which record was found was that conducted by G. T. W. Patrick and J. A. Gilbert [1] in 1896. These two men worked with three subjects who abstained from sleep for a period of ninety hours, one of them with very serious results. Their findings had to do merely with the immediate effects of the loss of sleep. In 1916, Miss May Smith,[2] an Englishwoman, conducted an experiment in which she herself acted as subject, and she, for the first time so far as was ascertained, investigated the remoter effects of the loss of sleep, viz., the length of time required for a return to a normal condition after sleep had been taken, and the duration of physical and mental inefficiency induced by the lack of sleep, as well as the immediate results, viz., immediate physical and mental reactions. In 1922 at the University of Chicago, E. S. Robinson and F. Herrmann,[3] two graduate students, conducted an experiment very similar in nature to

[1] Patrick, G. T. W., and Gilbert, J. A., 'Effects of Loss of Sleep,' *Psychological Review*, 1896, No. 3, pp. 469–483.

[2] Smith, May, 'Contribution to the Study of Fatigue,' *British Journal of Psychology*, 1916, No. 8, pp. 327–350.

[3] Robinson, E. S., and Herrmann, F., 'Effects of the Loss of Sleep,' J. of Exp. Psychology, 1922, No. 5, pp. 19–32; 93–100.

this. Their first experiment was later followed by another in which a greater number of subjects was used.

The purpose of this experiment was to measure in an objective manner the effects of fatigue induced by the loss of sleep; and, not only to determine the immediate effects, but to determine the remoter effects as well. It was with this end in view that the administration of the tests was continued for a week following the actual period of sleeplessness, during which time the remoter effects were measured. In order to eliminate the influence of the practice factor in the administration of the tests, the administration was begun a week before the period of insomnia, and during the period of insomnia, the tests were given at the greater frequency of six hours, so that more closely the immediate effects might be measured.

The effects of fatigue, whether produced by the lack of sleep, or in any other manner, are of vital importance in any walk of life. In this age, industrial fatigue is very prevalent and is an important factor in the matter of production. It has been shown that more can be turned out and better work secured in a ten-hour day than in a twelve-hour day, and the amount of reduction in output due to the eight-hour day is counterbalanced by the raising of the standard of quality. In the educational field likewise there are many aspects to the problem. Our changing ideals with respect to recreation are taxing the strength of the youth. What are these effects upon school work? Dare recreation be indulged in at the expense of bodily fatigue? Does cramming aid a student in preparing for recitation or examination? These and similar questions are involved.

Method of Procedure

This experiment extended over a period of seventeen days, January seventh to twenty-third, inclusive, 1925. The writer acted both as subject and experimenter. On the ninth, tenth, and part of the eleventh days of the experiment, January 15th, 16th and 17th, no sleep was taken. The experiment was controlled by means of a series of mental and physical tests during the entire period.

The first test was that of memory. Nonsense syllables were used composed at random according to the method used by Meuman. During the first eight days preceding the period of insomnia, a set of fifteen syllables was presented each day, and by means of a stopwatch the absolute time in seconds required to learn the set twice beyond the threshold was noted. The same procedure obtained during the six days following the period of insomnia. During the period of insomnia, the tests were given at intervals of six hours, beginning at midnight of January 15th; again at 6:00 A.M. of January 16th; 12:00 noon of January 16th; 6:00 P.M. of January 16th; 12:00 midnight of January 16th; 6:00 A.M. of January 17th; 12:00 noon of January 17th; and 6:00 P.M. of January 17th. This method of procedure held in all the tests, namely, once a day during the weeks preceding and following the period of insomnia, and at intervals of every six hours during that period. On the day following the learning of each set of nonsense syllables, that set was relearned and the time in seconds required for relearning was noted as described above.

The second test was that of speed. A column of figures, consisting of fifteen numbers of seven digits each, a combination sufficiently large to cause some difficulty, was presented for addition. The correct answer to each column was given at the bottom of the stimulus card and that answer was worked for, the absolute time in seconds required to obtain the correct answer being noted by means of a stopwatch and used as a measure of speed. Tests were given at intervals described above.

The third test was that of accuracy, in which Whipple's A Test was used. Each test given contained 100 A's. Forty-five seconds were allowed in which to cancel as many A's as possible. Record was made of the number of letters cancelled, of the number of letters wrongly cancelled, of the number of A's erroneously omitted, and the score was computed according to the formula for accuracy as given by Whipple:[1]

[1] Whipple, 'Manual of Mental and Physical Tests,' Vol. 1.

$$\text{Accuracy} = \frac{\text{no. of letters crossed minus no. of letters wrongly crossed}}{\text{no. of letters crossed plus no. of letters erroneously omitted}}.$$

Thus it is seen that not only is the accuracy measured but the greater amount of speed attained with that accuracy, the less the effect of errors upon the score of accuracy. These tests were likewise administered at the same periods of time as the others described above.

A record of the pulse rate was obtained daily by an assistant, except during the period of insomnia when, as in the cases of the other tests, this was obtained at six hour periods. A record of the weight was kept, the weight being taken at intervals of two days except during the period of insomnia when it was obtained daily.

Throughout the entire experiment introspections were made at any time need was felt for keeping desirable notes, regarding appetite, feelings, impressions, general health, etc. Every effort was made to keep conditions constant during the experiment and to eliminate any variability which might tend to creep in to invalidate the results. The tests were administered at the same time each day under uniform conditions. No rules were enforced and no regulations imposed except those involved in the administration of the tests —the regular normal life was lived. The total period of insomnia was of sixty-two hours duration, from 7:00 o'clock in the morning of Thursday, January 15th, until 9:00 o'clock in the evening of Saturday, January 17th. During the total period of the experiment the subject went about his daily duties. At the beginning of the experiment the subject was in good health except from the effects of a winter cold.

Introspective Notes

Although no physical examination was given immediately preceding the experiment, there was no noticeable ailment which caused the subject any physical discomfort, except, as has been mentioned, the presence of a moderately severe cold

which was at its worst on the third, fourth, and fifth days of the experiment. The effects of this cold are noticeable in the curve of the pulse rate, where there is the high rate of 86 beats per minute for three consecutive days; and in the curve of weight where there was a drop during that time, the lowest during the entire period. For the week preceding the period of insomnia the appetite was poor. Little was eaten at meal times and nothing between meals, a condition which may have been due to the effects of the cold from which the subject was suffering. However, with the beginning of the period of insomnia there was a marked increase in the amount of food taken—the appetite was keen, all kinds of food were appealing and the desire for food was felt at any hour of day or night.

The period of insomnia began in reality with the first night on which no sleep was taken, although the subject did not sleep after 7A.M. of the day of January 15th. During the first night no severe hardship was experienced, in fact, after midnight there was no real desire to sleep. The night was spent at various tasks, work which included reading and writing, solitaire, short walks, letter writing; no one kind of occupation was engaged in for more than an hour and a half at a time—variety was sought. There was a slight nervous tension which continued throughout the night but which disappeared in the morning; the tendency to jump at slight noises was strong, and noises which ordinarily would never have been heard were extremely accentuated—a condition which was also reported by Smith and Robinson. There was a general tired feeling in the limbs, and after sitting for any length of time there was noticeable a lack of equilibrium and a feeling of mild intoxication which continued to increase as the period of sleeplessness was prolonged, a feeling which, however, was void of any of the pleasurable effects of intoxication. When walking there was a tendency to drag the feet instead of to lift them. A slight indigestion was felt which doubtless was due to an overuse of stimulants and narcotics. With regard to mental vigor, these findings agree in the main with those of Smith. There was a feeling of

mental exaltation which enabled the completion of a great amount of work, but this feeling never approximated that feeling attained by Smith, who in her description says that it was a feeling of mental exaltation "combined with an emotional belief in the power to conquer all things"; and although there was physical tiredness, it never "became at times positive pain." In further corroboration of Smith's results, there was noticeable a certain reluctance to begin any sort of work—the assumption of a position of comfort was more preferred—but, after any task was begun, sources of reserve energy seemed to be tapped which enabled the carrying of the task through to completion.

The following day was spent in the usual way, classes, a bit of study and some recreation. The general physical condition was for the most part excellent. There was a freshness felt during the morning which often was not experienced after a night of sleep. Late in the afternoon a heaviness of the eyelids was again experienced and an extremely sleepy feeling which had to be stubbornly fought off, usually successfully by a few breaths of fresh air.

The second night can be divided into two periods, each characterized by certain feelings. The first was characterized by great mental activity—sleep probably would have been impossible had it been desired. The desire to remain awake which had been in the process of building during the past thirty-six hours had established neurological connections which would have had to have been broken down before sleep could have been induced. However, the character of the work accomplished was not of as high a standard as that of the night previous. There was a decided lack of concentration and much waste movement. The second stage was characterized by a sandy feeling in the eyes, extreme heaviness of the muscles, awkwardness of movement, nervousness to the extreme, headache. At times a condition very like a trance seemed to come on in which the muscles set tightly, the mind became perfectly blank and the eyes refused to function, although they remained wide open. When suddenly consciousness was restored it seemed that that condition must

have lasted for a minute or more, and the regaining of consciousness was usually accompanied by a sickly sort of feeling akin to the feeling which is experienced when an unnatural or abnormal sight or sensation is experienced. There was a still greater amount of waste movement and meaningless activity which appeared ridiculous to the assistant and served even then as a source of amusement to the subject when enough power of concentration was mustered to analyze such movements. There was a great lack of inhibition, which gave to all actions the general characteristics of action during intoxication. However, there was not yet any great desire to sleep. Loss of motor control, dizziness, light-headedness and nervousness are all likewise reported by Robinson.

The following, or third, day without sleep marks the final stage of the period, a stage when continued abstinence from sleep did become real positive suffering. It is strange that such an effect should have been experienced during the daytime, a time when it would naturally seem abstinence would be the easiest. Gilbert and Patrick report that the hardest period to remain awake was during the night of the second day and that when there was daylight it was always relatively easy to remain awake. In this case, however, it was just about daybreak, shortly after seven o'clock in the morning, when a nigh irresistible desire to sleep was experienced, a condition which continued throughout the day. It was not safe to sit down a minute—there was a tendency to drop off at any time and in any position. Reading was impossible. It was only with great difficulty that it was possible to take the required tests as they were administered, and the effect of the utter inability to concentrate for more than a few seconds at a time is noticeable in the curves of the results. The bodily temperature dropped greatly—it required a temperature of 80 degrees F. before comfort was felt and yet at such a temperature it was impossible to hold the eyes open. Practically the entire day was spent in walking from one place to another in a conscious effort to remain awake. Every movement was effort and there was no spontaneity about any activity. At the end of the period of insomnia,

there was some slight difficulty to induce sleep in spite of the extreme fatigue, and the sleep which followed, although only of fourteen hours duration, was frequently broken. No limit was set to the amount of sleep allowed, the subject taking as much as was desired, but the character of the sleep was noticed and observed to be of no very deep nature. The sleep on the second night after the period of insomnia, while of but nine hours duration, was of a more restful nature.

Discussion of the Results

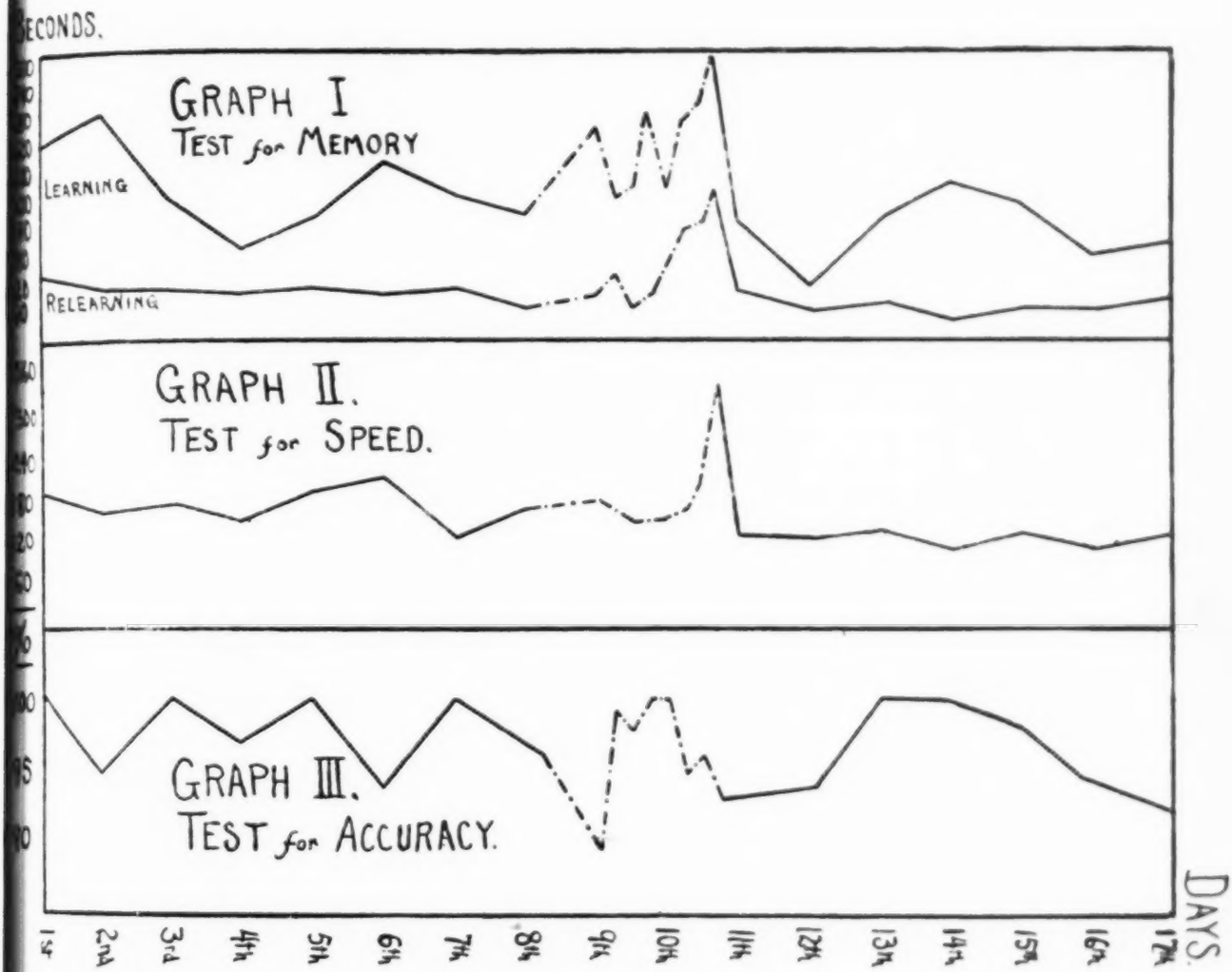
Before making comparisons with the results from similar experiments it will be well to take a brief glance at the data which have just been presented. In Table I. and Graph I.

Table I

Results from Nonsense Syllable Test for Memory. Score in Seconds, Day by Day, for Pre-Insomnia, Insomnia, and Post-Insomnia Periods

Test	Date	Learning	Relearning	
		Seconds		
1st	Jan. 7	405	127	Pre-insomnia Period.
2d	" 8	475	112	
3d	" 9	294	102	
4th	" 10	189	90	
5th	" 11	244	107	
6th	" 12	370	93	
7th	" 13	308	105	
8th	" 14	265	65	
Average		318.75	100.13	
9th	Jan. 15 12 midnight	445	120	Insomnia period.
10th	" 16 6 A.M.	306	155	
11th	" 16 12 noon	328	90	
12th	" 16 6 P.M.	520	120	
13th	" 16 12 midnight	310	170	
14th	" 17 6 A.M.	515	235	
15th	" 17 12 noon	525	247	
16th	" 17 6 P.M.	601	315	
Average		443.75	181.50	
17th	Jan. 18	251	120	Post-insomnia period.
18th	" 19	120	60	
19th	" 20	242	85	
20th	" 21	345	58	
21st	" 22	285	69	
22d	" 23	180	68	
Average		233.83	76.67	

are presented the effects obtained as measured with respect to memory. The general trend in both curves, for learning and for relearning, barring the period of insomnia, in downward showing a gain in proficiency. However during the



GRAPHS I-III

period of insomnia the marked and sudden upward trend of both curves, especially during the latter part of that period when concentration was low, is very evident. For learning, the average for the total time during which sleep was taken, *i.e.*, for the pre-insomnia and post-insomnia periods is the sum of the scores for those periods divided by the number of tests administered or 283.29 as compared with the much higher average during the insomnia period of 443.75. Likewise the average score for relearning during the entire period

during which sleep was taken is 90.07 as compared with the relatively high score during the period of insomnia of 181.50. In this test more than in any of the others the effects of the loss of sleep are noticeable, because, in all probability, of the greater necessity of concentrated effort in taking the tests. In these tests alone, unlike those for accuracy and speed where a certain amount of physical activity accompanied the mental activity, mental effort only was employed, a situation, which because of the lack of accompanying physical effort made concentration more difficult.

TABLE II

RESULTS FROM CALCULATION TEST FOR SPEED. SCORE IN SECONDS, DAY BY DAY, FOR PRE-INSOMNIA, INSOMNIA, AND POST-INSOMNIA PERIODS

Test	Date	Seconds	
1st	Jan. 7	185	Pre-insomnia period.
2d	" 8	140	
3d	" 9	145	
4th	" 10	131	
5th	" 11	193	
6th	" 12	217	
7th	" 13	129	
8th	" 14	142	
AVERAGE		160	
9th	Jan. 15 12 midnight	177	Insomnia period.
10th	" 16 6 A.M.	174	
11th	" 16 12 noon	150	
12th	" 16 6 P.M.	156	
13th	" 16 12 midnight	152	
14th	" 17 6 A.M.	155	
15th	" 17 12 noon	215	
16th	" 17 6 P.M.	335	
AVERAGE		192	
17th	Jan. 18	131	Post-insomnia period.
18th	" 19	130	
19th	" 20	141	
20th	" 21	115	
21st	" 22	140	
22d	" 23	118	
AVERAGE		129	

Table II. and Graph II. for speed show likewise a general gain in efficiency in the gradual downward trend of the curve, except for the period of insomnia; but during the latter part of the period of insomnia there is a sudden and extreme rise in the curve and in the scores for speed which immediately

seeks a normal level after sleep has been taken. The slight plateau reached on the fifth and sixth days of the experiment might be attributed to the generally poor physical condition due to the aforementioned cold in which the subject was at that time, especially since a similar lack of efficiency is to be

TABLE III

RESULTS FROM A TEST FOR ACCURACY. SCORE IN PER CENT. ACCORDING TO WHIPPLE'S FORMULA, DAY BY DAY, FOR PRE-INSOMNIA, INSOMNIA, AND POST-INSOMNIA PERIODS

Test	Date	No. Letters Cancelled	No. Letters Wrongly Cancelled	No. Letters Omitted	Accuracy	
1st	Jan. 7	48	0	0	1.00	
2d	" 8	58	2	0	.95	
3d	" 9	57	0	0	1.00	
4th	" 10	61	0	2	.97	Pre-insomnia period.
5th	" 11	53	0	0	1.00	
6th	" 12	62	2	2	.94	
7th	" 13	54	0	0	1.00	
8th	" 14	59	0	2	.97	
AVERAGE		55.75	0.50	0.75	.9788	
9th	Jan. 15 12 night	53	4	5	.90	
10th	" 16 6 A.M.	44	0	1	.99	
11th	" 16 12 noon	54	0	1	.98	
12th	" 16 6 P.M.	48	0	0	1.00	
13th	" 16 12 night	50	0	0	1.00	Insomnia period.
14th	" 17 6 A.M.	41	1	2	.95	
15th	" 17 12 noon	46	1	1	.96	
16th	" 17 6 P.M.	40	1	2	.93	
AVERAGE		47.00	0.875	1.50	.9638	
17th	Jan. 18	53	0	0	1.00	
18th	" 19	50	1	2	.94	
19th	" 20	58	0	0	1.00	Post-insomnia period.
20th	" 21	63	0	0	1.00	
21st	" 22	59	0	1	.98	
22d	" 23	48	1	2	.94	
AVERAGE		55.17	0.33	0.83	.9767	

seen in the other curves at about the same place. During the first day, first night and second day of the period of insomnia there is no visible effect upon the speedcurve: the scores were all approximately average. It was during the latter part of the sleepless period, when the powers of concen-

tration were shaken, that the rapid rise in the curve takes place. The mean score for the total period during which sleep was taken, found by dividing the sum of the scores by the number of tests taken, is 147, as compared with the considerably poorer score of 192 for the period of insomnia.

With respect to accuracy, Table III. and Graph III., the same general story is told; although the fluctuation in accuracy from day to day makes it exceedingly difficult to determine any very definite effect upon it from the loss of sleep. Yet the fact that during the period of insomnia we find the lowest score for accuracy is very significant. Throughout the entire experiment, the scores for accuracy ranged between the very limited area of 100 per cent. and 90 per cent. The constant fluctuation seems to preclude any trace of such a factor as practice. Only at two times was there obtained the same score for two consecutive days and one of these times occurred during the period of insomnia when the score was 100 per cent. Even towards the end of the period of insomnia, when in the other tests the lowest scores were obtained, we find two perfect scores, and the other scores for this period are not as low as some of the scores made before and after the sleepless period. The lowest score made during the entire experiment in accuracy did, however, come immediately at the start of the period of insomnia, where it is possible and probable that the great amount of nervousness would show up in a test of this kind where motor-coördination as well as mental alertness played a rôle. It is only by taking the averages that any results are to be seen at all, and then the difference between the periods, that in which sleep was taken and that in which sleep was not taken, is so slight that any conclusions are hardly warranted. The mean score for the period during which sleep was taken, *i.e.*, the pre-insomnia and post-insomnia period, found by dividing the sum of the scores by the number of tests, is .9779 as compared with the slightly lower score of .9638 for the sleepless period. It will be noticed that in the other tests the lowest scores came on the second night and third day of the period of insomnia, while in this case there is little fluctuation from the average

at those times, as a cause of which we have already suggested the physical activity as well as the mental concentration which was entailed.

The interesting features of Table IV. and Graph IV. are the rise in the pulse rate for the three days, the third, fourth and fifth during which there was the physical indisposition; the extreme slowness of the pulse rate during the latter part of the period of insomnia where the number of beats per minute dropped to the very low score of 52, a period which was accompanied by a low degree of vitality and a low bodily temperature; and, the immediate return of the pulse rate to the normal after sleep was taken.

TABLE IV

PULSE RATE. SCORE IN NUMBER OF BEATS PER SECOND, DAY BY DAY, FOR PRE-INSOMNIA, INSOMNIA, AND POST-INSOMNIA PERIODS

Test	Date	Beats per Second	
1st	Jan. 7	78	
2d	" 8	84	
3d	" 9	86	
4th	" 10	86	Pre-insomnia period.
5th	" 11	86	
6th	" 12	74	
7th	" 13	77	
8th	" 14	74	
9th	Jan. 15 12 midnight	74	
10th	" 16 6 A.M.	72	
11th	" 16 12 noon	76	
12th	" 16 6 P.M.	68	Insomnia period.
13th	" 16 12 midnight	63	
14th	" 17 6 A.M.	59	
15th	" 17 12 noon	57	
16th	" 17 6 P.M.	52	
17th	Jan. 18	70	
18th	" 19	79	
19th	" 20	72	
20th	" 21	76	Post-insomnia
21st	" 22	78	
22d	" 23	72	

Table V. and Graph V. present an interesting study in weight, and these statistics, together with those presented in Table IV. and Graph IV. tell a fairly accurate story of the general physical condition during the course of the entire experiment. The curve in Graph V. is generally upward, even during the period of insomnia, showing a gradual

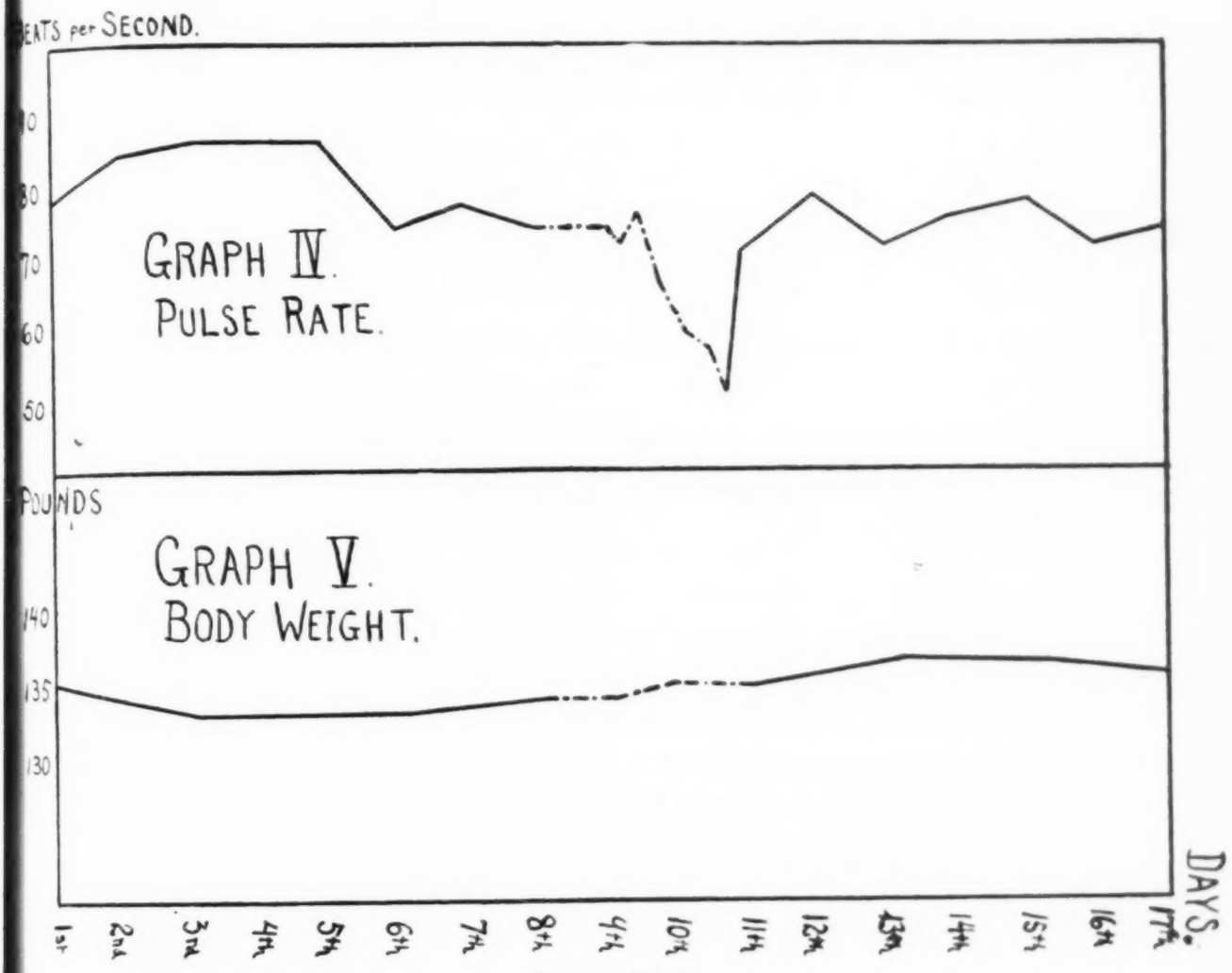
TABLE V

BODY WEIGHT. SCORE IN POUNDS, DAY BY DAY, FOR PRE-INSOMNIA, INSOMNIA, AND POST-INSOMNIA PERIODS

Test	Date	Pounds	
1st	Jan. 7	135	Pre-insomnia
2d	" 9	133	
3d	" 12	133	
4th	" 14	134	
AVERAGE		133.75	
5th	Jan. 15	134	Insomnia period.
6th	" 16	134	
7th	" 17	135	
AVERAGE		134.67	
8th	Jan. 19	136.5	Post-insomnia period.
9th	" 21	136.5	
10th	" 22	136.0	
11th	" 23	136.0	
AVERAGE		136.25	

increase in weight. The only downward trend is during the third, fourth and fifth days when the general physical condition, due to the cold from which the subject was suffering, was not at best. Immediately following this slight decrease, there was a slow but steady rise until near the end of the experiment. The fluctuation in weight was never great, ranging only from 133 pounds at the lowest to 136.5 pounds at the highest. This, according to the belief of many, should be a fairly correct index of the general physical condition. There are many who hold that the health of the body is reflected by the weight, and Avery O. Craven, sometime prominent director of scholastic athletics at North Division High School, Milwaukee, trained his teams and whipped them into condition mainly by watching the individual weights of his men. Under proper conditions of health the weight should not vary from day to day more than one and a half to two pounds. The steady rise in the weight might be accounted for as being due to the tremendous appetite which began at the outset of the period of insomnia and continued for several days following. The cause for this sudden and marked increase in appetite is most easily explained as being an evidence of Nature supplying the physical needs of the body

through the appetite when unable to supply those needs through sleep. The loss of sleep was offset by supplementing the amount of energy needed by an increase in food.



GRAPHS IV–V

A comparison of these various Tables and Graphs will show certain features which are common to all. It is first seen that during the first half of the period of insomnia practically no effects due to the lack of sleep are noticed, except in the case of the tests for accuracy; but that during the latter half of the period, particularly during the third day, there was a rapid decrease in mental efficiency. Another interesting aspect is found in the fact that immediately after sleep was taken there was a return to the normal, and from then on the scores were better than before the period of

insomnia, again with the exception in the case of accuracy where they tend to remain about the same.

On the whole, the results obtained tend to conform more closely with those obtained by Patrick and Gilbert and by Robinson and Herrmann rather than with those obtained by Miss Smith. Patrick and Gilbert in their experiment worked with three subjects who abstained from sleep for a period of 90 hours during which time control tests were given periodically every six hours. Robinson and Herrman conducted an experiment which was very similar in nature to this. Their period of insomnia was approximately 60 hours and they made an attempt to measure the after effects, a thing which Gilbert and Patrick did not do. However in both these experiments, so far as was able to be discerned, it was found that a period of sleep, even though only of the average length of eight hours, caused an immediate return to the normal—which is the result in this case also. Miss Smith came to different conclusions from her investigation. Her experiment was of a slightly different nature. She worked with herself as subject and induced fatigue through loss of sleep in the following manner: on three successive nights she curtailed the amount of sleep which was ordinarily taken; the first-night taking one and a half hours sleep; the second night taking three and a half hours sleep; and the third night taking five and a half hours sleep. Her control was through a series of tests: a tapping test, an association word test, a memory test of nonsense syllables and others of lesser importance. She found that there was at first a period of stimulation due to the first effects of fatigue, and that any serious effects did not tend to show up until what she terms the "second stage." So far we will agree with her in her findings. But, for a period of sixteen days after the period of insomnia she found that there was a marked deficiency in the scores of all tests and it was not until about the sixteenth day that the scores returned again to normal. In this finding she stands alone, neither Robinson nor Patrick supporting her—nor do the scores from this experiment show such a condition.

However, before anything definite can be said about the validity of either of these two sets of findings, more work must be done along this line. More subjects must be worked with and the experiment should cover a longer period of time in all phases; the period before the sleepless stretch should be lengthened, where possible a longer period of insomnia might bring to light further results, and the period following the insomnia should be more closely watched. Patrick and Gilbert made no attempt to measure the after effects in any scientific manner. Robinson and Herrmann obtained no very definite results of the after effects which they frankly admit. In concluding they say, "The main conclusion . . . is that the results of the tests were not affected by the insomnia in any marked or consistent manner." [1] And if any conclusions can be drawn at all they must necessarily be that the results of insomnia were negative, for "attempts to measure the magnitude of the effects of loss of sleep by means of standard test procedures brought practically negative results." [2]

In this experiment, we feel that we were handicapped through the lack of a sufficiently large number of subjects; and because of the fact that some familiarity with the tests was unavoidable despite all efforts to the contrary, since the subject and experimenter were the same. Practically the only point where there is any general agreement whatever on the part of those who have already done work in this field is in the observance of a certain period of stimulation which proceeds the general mental decline. Psychologists and educators hold that a change of occupation is restful and that it is possible to be mentally alert even when physical vigor is at a minimum. It is a state somewhat similar to this which we believe existed in this and other similar experiments, which gave the appearance of a period of stimulation. However, any extended degree of fatigue is not advisable and might even prove serious.

[1] Robinson and Herrmann, 'Effects of the Loss of Sleep,' J. of Exp. Psychol., 1922, No. 5, p. 30.

[2] *Ibid.*

Conclusions

While we do not feel justified, for reasons already stated, in drawing any sweeping or far reaching conclusions, there are certain features which tend to stand out conspicuously from the results obtained. These we present, not in any dogmatical fashion, but for purposes of consideration and comparison:

1. Fatigue induced through the loss of sleep to a certain point acts as a stimulant upon the mental powers.

2. Unless continued to a great length, loss of sleep does not seem to affect either the mental or physical powers to any appreciable degree.

3. After a certain point, loss of sleep effects the mental powers to a considerable degree, acting upon them indirectly through the diminishing of the power of concentration.

4. Memory and speed seem to be more greatly affected than accuracy.

5. From the findings obtained in the measurement of weight, it would seem that, to a certain limit, nature restores the energy lost through lack of sleep and that hidden stores of surplus energy are drawn upon. It would therefore follow, that the amount of sleep which can be lost without serious results would depend upon the constitution of the individual.

6. Bodily temperature and pulse rate are both lowered by continued loss of sleep.

7. It requires but little sleep more than that ordinarily required to recuperate from the effects of loss of sleep.

8. The dangers accruing from loss of sleep occur in cases where this loss is prolonged beyond certain reasonable limits, or where such loss is habitually repeated.

AN EXPERIMENTAL STUDY ON RETINAL SENSITIVITY AND DISCRIMINATION FOR PURPLE UNDER DIFFERENT DEGREES OF INTENSITY OF STIMULATION [1]

BY FRANKLIN O. SMITH

State University of Montana, Missoula, Montana

Introduction

The main motive for the present experiment was the desirability of demonstrating a simple and direct method of determining a scale of just-perceptible difference of purple.

Retinal sensitivity for hue differences has been very widely investigated for spectral colors. In 1906 Steindler[2] published results of measurements on the discrimination of colors in terms of wave-length and from data obtained on twelve subjects he plotted the average sensibility curve for spectral colors. He found three points of maximum sensibility, namely 621$\mu\mu$, 535$\mu\mu$, 458$\mu\mu$ respectively, between 400$\mu\mu$ and 700$\mu\mu$, and four points of minimum sensibility namely 637$\mu\mu$, 580$\mu\mu$, 592$\mu\mu$, and 440$\mu\mu$ respectively.

In 1917 Mr. Arthur L. Jones[3] reported an especially important investigation from the Research Laboratory of the Eastman Kodak Company, in which he determined by spectrophotometric methods the relation existing between the wave length units and the least perceptible sensation difference for spectral colors. The method as described by Jones gave a direct determination of the scale-reading curve and involved the use of the least perceptible hue differences as the actual

[1] The present study was aided by a grant from the American Association for the Advancement of Science. Further studies on related problems are in progress.

[2] Steindler, O., Ak. Wiss., Wien, Jan., 1906, 115; quoted by Jones, *Journal of the Optical Society of America*, 1917, Vol. 1, 66.

[3] Jones, A. L., 'The Fundamental Scale of Pure Hue and Retinal Sensibility to Hue Differences,' *Jour. Op. Sc. of Am.*, 1917, Vol. 1, 63–77.

unit of measurement. Using this difference as the unit of length he measured off step by step the entire spectrum.

Letting equal units on the y axis represent least perceptible differences and similar equal increments on the x axis represent consecutive wave-length units of the spectrum (400 to 700$\mu\mu$) Jones obtained the sensibility curve of the retina to hue differences. Within these limits he found 128 just perceptible hue differences.

Ferree and Rand [1] have made extensive investigations on chromatic thresholds of sensitivity from center to periphery of the retina for different colors and for varying intensities. It appears from their results that over a considerable area in the central region the intensity thresholds for blue and green are lower than for red and yellow, and further "that the sensitivity of the retina falls off gradually to a point within 5 degrees of the limit and from that point to the limit it falls off very abruptly." [2] The limit varies for different colors in the order, green, red, yellow and blue.

The determination of the required j.n.d. on a pure hue scale obviously involves the measurement of differences in wave length of as nearly monochromatic light as possible illuminating the two fields which appear just noticeably different in hue. In the case of spectral colors this can easily be accomplished by means of a spectroscope of the Hilger type, provided with a special collimating system by which it is possible to vary a two part phometer field by changing the angular distance of the collimating systems.[3]

This method, however, is applicable only directly to the comparison of single spectral hues and not to mixtures, such as purple. Since it is not possible to measure the j.n.d. of purple in terms of wave-length units, Jones suggested a method whereby a mixture of the given purple with mono-

[1] C. E. Ferree and Gertrude Rand, 'Chromatic Thresholds of Sensation from Center to Periphery of the Retina and their Bearing on Color Theory.' *Psychol. Rev.*, 1919, Vol. 26, 16–41; 150–163.

[2] Rand, Gertrude, 'Factors that Influence the Sensitivity of the Retina to Color,' *The Psychol. Monog.*, 1913, Vol. 15, No. 1, p. 105.

[3] For an excellent summary and criticism of the methods of color photometry the reader is referred to Luckiesh, 'Color and Its Applications,' Chapter IX.

chromatic light may be made so as to produce a sensation of white. The terms of the color specification in this case will be the wave-lengths of the complementary hue and the per cent. of monochromatic light in the mixture. Using midday sunlight as a standard white he employed this method to determine the dominant hue values of six purples proposed by Ridgeway in his book, 'Color Standards and Nomenclature.' [1] The range of these purples from bluest to reddest was found to lie between the complementaries 570 and 512$\mu\mu$. No determination of the actual number of discriminable purples was made.

This method presents certain disadvantages not-withstanding its practical utility. Its validity depends upon the validity of the assumption that the just perceptible differences in the complementary of a given purple are equivalent to the just perceptible differences in the purple. This assumption needs to be further investigated.

It seemed, therefore, desirable to determine by direct photometric method the sensibility of the retina for purple obtained by mixing red and blue under specified conditions of purity and intensity of illumination.[2]

Conditions under which the Experiments Were Made

Since purple can be produced only by mixing other colors, as red and blue, it is desirable to use as nearly pure monochromatic light as possible in the mixture. And since there seems to be no simple direct method of measuring the mixture of two lights in wave length units, we are limited to the use of one of several methods of mixing colored light from pigments.

A very pure color may be obtained by the use of the Wratten Filters made by the Eastman Kodak Company. These filters have been standardized by spectrophotometric methods and charts have been constructed showing the wave-length limits of each filter under specified conditions of illumination, and density.

[1] Jones, *op. cit.*, p. 73.

[2] Sinden has recently published the results of such a study for the purpose of investigating subjective saturation of spectral hues. His method was similar to that of Jones mentioned above.

The requirements of these experiments were met by the use of red and blue filters. The wave length limits of these filters are approximately 650 and 700$\mu\mu$ for red and 400 to 490$\mu\mu$ for blue. The means for the filters are therefore, approximately 670 and 450$\mu\mu$ respectively. The transmition of incident light is 25 per cent. for each filter. These specifications are merely for the description of the conditions under which the experiments were made.

It is evident, since purple cannot be measured directly in terms of the wave length of radiation, that, if a scale of perceptible purples is to be established, the points on that scale must be designated in the least perceptible difference as measured in terms of the proportions of red and blue in the mixture.

The terms of the color specification will then be the relative intensity of the red and blue lights in the mixture on a two-part photometer field either part of which may be varied independently.

The experiments were performed in a darkened room, all the windows being supplied with heavy black shades. Between observations the Ss fixated a large black cloth supported before the eyes.

To determine the effect of varying the intensity of stimulation three intensities of the illuminating source were employed, namely, high at 162 Meter Candles incident on the photometer field, medium at 21 M.C. and low at 7.8 M.C. A more accurate statement of the conditions of illumination would require that the distribution of radiant energy in the red and blue light in the different lamps under consideration be plotted. A still greater degree of refinement would have consisted in the use of an artificial pupil to control the intensity of stimulation on the retina.[1]

The usual difficulties encountered in color photometry when monochromatic light from widely separated parts of the spectrum are compared were greatly lessened in the present experiment by the fact that one component of the

[1] Troland, Leonard T., 'On the Measurement of Visual Stimulus Intensities,' JOURNAL OF EXPERIMENTAL PSYCHOLOGY, II., 1917, pp. 1–3.

purple was varied, the other remaining constant through a series of tests; that is red, *e.g.*, was constant at maximum intensity while blue was varied step by step from zero to maximum intensity. The brightnesses of the four lights on the photometer field were equated by the direct comparison method before inserting the filters. The problem then consisted in comparing the two halves of the photometer field illuminated by colors of the same hue and saturation and differing by a just perceptible difference in intensity.

Description of the Apparatus

The requirements of the experiment were met by projecting the light from four Tungsten lamps, after passing through the red and blue filters, upon the two part photometer field. The latter consisted of a 90 degree reflecting wedge made of polished brass and covered with magnesium smoke. The lamps *b*, *b*, *b*, *b* (see Fig. 1), arranged in pairs on opposite sides of the two part photometer field *W* are enclosed in tin boxes 1*b*, 1*b*, 20 inches long, 20 inches high and 16 inches wide. The two lamps of a pair are separated by a vertical asbestos partition, *p*, through the center of each box. Between these boxes is a projection chamber 42 inches long, 8 inches high and 12 inches wide. In the center of this projection chamber midway between the light sources is the two-part photometer field *W* which consists of the reflecting wedge mentioned above. Exactly over the center of the edge of the reflecting wedge, that is to say, over the photometer field, is an eye piece consisting of a brass tube *t* 6 inches long and 1¼ inches in diameter with an objective lens at the upper end.

The two lamps of each pair being separated by an angular distance of 10 degrees, a beam of light from each source is projected upon the photometer field after passing through one of the four Wratten Filters *f*, *f*, *f*, *f*. The filters are arranged in pairs, a red and a blue on either side of the reflecting wedge, thus producing a field of purple from the mixture of red and blue light upon each half of the photometer field. The intensities of the four lights were controlled by means of series of diaphragms, *d*, *d*, *d*, *d*, with aperatures varying by 64th of an inch from zero to 1⅛ inches in diameter.

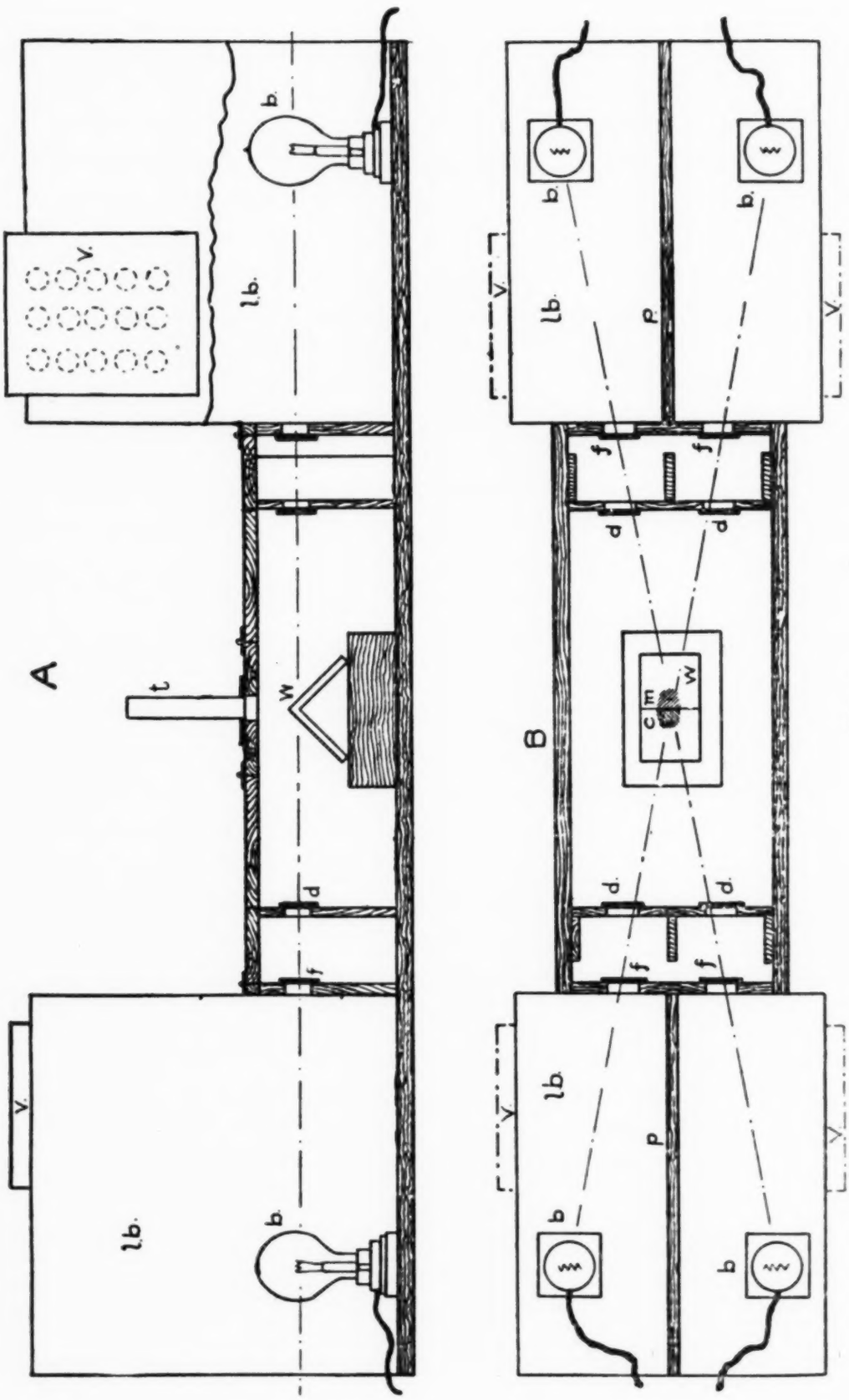


FIG. 1

The filters were inserted between the sources of light and the diaphragms in order to vary the intensity of monochromatic light on the photometer field and therefore on the retina without varying the saturation.

A round aperture at the lower end of the brass tube exposed a circle of purple about one inch in diameter the intensity of the right or left half of which could be varied independently by inserting the proper diaphragm. The size of the photometer field is not material to the measurement of retinal sensitivity. It was found, however, that it was possible to obtain a perfect mixture of red and blue components only on a limited portion of each half of the two-part photometer field. Hence the small opening at the bottom of the tube was necessary to secure a homogeneous field.

Before beginning an experiment the four light sources were carefully adjusted so as to produce equal intensities on the two-part photometer field. One lamp was taken as the standard at .7 meter from the photometer and the others adjusted to it by varying their distances.

Procedure

Fifteen subjects were tested for each of the three intensities of stimulation. Owing to the time required to complete a series of tests for a given intensity and also to the fact that nearly all of the subjects were undergraduate students in psychology and could give only a limited time to the experiment it was not feasible to make complete tests for all three intensities upon one group of subjects, although this is highly desirable. However it is probable that no serious discrepancy between the results of tests upon different groups has occurred as a consequence of using different subjects for different intensities. In some cases the same subjects took two series of tests, namely, the one for the lowest and the one for the medium intensity. In addition to the undergraduate students in psychology three other subjects should be mentioned, one a professor in physics, and two graduate students in psychology.

After preliminary training to determine the reliability of the subject, to accustom him to the experiment and to secure

the initial effect of practice the experiment proceeded in the following manner: Each half of the photometer field being illuminated by 100 per cent. of red and one half having zero per cent. of blue, the other half was illuminated by a very small amount of blue. This was increased step by step by inserting diaphragms with larger aperatures until a first perceptible reddish purple appeared. This gives the threshold of sensitivity for the red end of the purple scale. Using this threshold as the basis of comparison the just perceptible difference at this point was determined. In the same manner the succeeding discriminable purples were determined step by step by the method of limits through the entire scale of reddish purples from minimum to maximum intensity of the illuminating source, *i.e.*, from 100 per cent. red and zero blue to 50 per cent. of each. This procedure was then repeated through the blue end of the purple.

Results

The Scale of Purples.—The total number of perceptible purples from minimum to maximum intensity of stimulation is shown to be 19 for low, 28 for medium, and 35 for high

Table I

Scale of Purple for Low Intensity

Red End of the Purple Scale				Blue End of the Purple Scale			
D	D^2	*R*	*dR*	*D*	D^2	*R*	*dR*
9.0	81.0	.0156	.0156	16.5	272.2	.053	.053
12.8	164.0	.032	.016	21.9	479.7	.093	.040
16.8	282.4	.054	.022	28.7	823.9	.159	.066
21.4	458.2	.088	.034	36.0	1296.0	.250	.091
26.8	718.4	.139	.051	43.9	1927.3	.372	.122
32.6	1063.0	.205	.066	52.4	2746.8	.529	.157
39.0	1521.0	.293	.088	61.7	3807.1	.734	.205
46.2	2134.6	.412	.119	71.6	5126.8	.989	.255
53.8	2894.6	.558	.146				
62.4	3894.0	.751	.193				
71.2	5096.6	.983	.232				

D Average diameters of the apertures (in the diaphragms) giving just perceptible differences of purple. These values are in 64ths of an inch.

D^2 Squares of the diameters. That is, the areas of the apertures. Since π is a common factor it is ommitted in the computations.

R Ratios of the given values to the maximum value, 72^2.

dR Scale of j.n.d.s derived from the *R* values.

TABLE I. (*Continued*)

MEDIUM INTENSITY

Red End of the Purple Scale				Blue End of the Purple Scale			
D	D^2	*R*	*dR*	*D*	D^2	*R*	*dR*
6.7	44.9	.008	.008	11.8	139.2	.025	.025
10.7	114.7	.022	.014	16.2	262.4	.051	.026
13.4	179.8	.034	.012	20.7	428.5	.083	.032
16.1	259.3	.050	.016	25.2	645.1	.122	.039
19.0	361.0	.070	.020	29.4	864.4	.167	.045
22.0	484.0	.093	.023	34.5	1156.0	.223	.056
25.3	640.3	.123	.030	39.0	1521.0	.293	.070
29.0	841.0	.162	.039	44.2	1953.8	.377	.084
33.0	1089.0	.210	.048	50.0	2500.0	.482	.105
37.3	1391.5	.268	.058	56.8	3249.0	.622	.140
42.0	1764.0	.340	.072	64.3	4134.7	.783	.166
47.0	2237.5	.431	.091	72.0	5184.0	1.000	.217
53.0	2809.0	.542	.111				
58.8	3457.6	.667	.125				
65.3	4225.0	.811	.144				
72.0	5184.0	1.000	.189				

TABLE I. (*Continued*)

VERY HIGH INTENSITY

Red End of the Purple Scale				Blue End of the Purple Scale			
D	D^2	*R*	*dR*	*D*	D^2	*R*	*dR*
7.0	49.0	.010	.010	8.0	64.0	.012	.012
10.4	108.2	.021	.011	12.2	144.0	.028	.016
13.8	180.4	.035	.014	15.8	249.6	.048	.020
17.0	289.0	.056	.021	19.4	376.4	.073	.025
20.1	404.0	.078	.022	22.8	519.8	.100	.027
23.3	542.9	.105	.027	26.4	697.0	.134	.034
26.5	702.2	.135	.030	30.0	900.0	.173	.039
29.8	888.0	.171	.036	33.6	1128.7	.221	.048
33.0	1089.0	.210	.039	37.2	1393.8	.269	.048
36.2	1310.4	.253	.043	40.8	1664.6	.321	.052
39.2	1536.6	.296	.043	44.4	1971.4	.380	.059
42.4	1797.8	.347	.051	48.4	2342.6	.452	.072
45.9	2106.0	.406	.059	53.0	2809.0	.542	.090
49.7	2470.0	.476	.070	58.4	3410.8	.659	.117
53.9	2905.3	.560	.084	64.6	4173.2	.805	.146
58.8	3457.4	.667	.107	71.7	5141.1	.991	.186
64.7	4186.3	.807	.140				
72.0	5184.0	1.000	.193				

illumination (Table I.). For each of the three intensities the scale is longer at the red than at the blue end. The ratios are 11 to 8, 16 to 12, and 19 to 16 for low, medium, and high intensity respectively.

Sensitivity.—The average threshold of sensitivity for the red end of the purple scale [1] is .012, .011 and .010 respectively for low, medium and high intensities. For the blue end it is .053, .027, and .012 respectively.

The Purkinje effect is seen in the large difference in sensitivity between the red and blue ends of the purple. The threshold of sensitivity of the retina to the blue component in the red end is .012 and to the red component in the blue end it is .047 or nearly four times as high (Table II.). At high intensity very little difference is noted, .011 and .012 respectively.

TABLE II

SHOWING THE THRESHOLD OF SENSITIVITY TO THE RED AND BLUE ENDS OF THE PURPLE SCALE RESPECTIVELY

	Red	Blue
Low	.0156	.053
Medium	.008	.025
Very high	.007	.008

Discrimination.—The successive just perceptible differences are slightly larger for the red than for the blue component in the purple. (Table I.) Both increase in magnitude

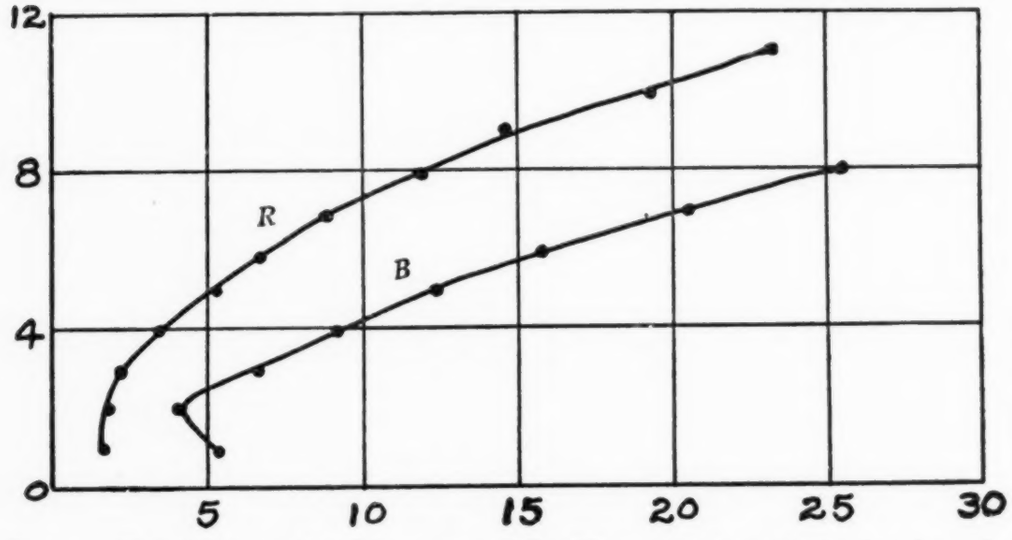


FIG. 2. Showing the scale of just perceptible differences of purple for low intensity of illumination. *R*, red end. *B*, blue end.

[1] It should be clear that we are measuring sensitivity for blue in the red end of the purple and for red in the blue end; for in the red end the blue component is varied step by step from minimum, *i.e.*, zero to maximum, while the red component on both halfs of the photometer field remains constant. Conversely the red in the blue end is varied while the blue remains constant.

from minimum to near maximum intensity of stimulation according to the requirements of Weber's Law. As maximum intensity is approached the size of the steps increase disproportionately. Approximately maximum illumination on the photometer field is afforded by an aperture of 1 ⅛ inch.

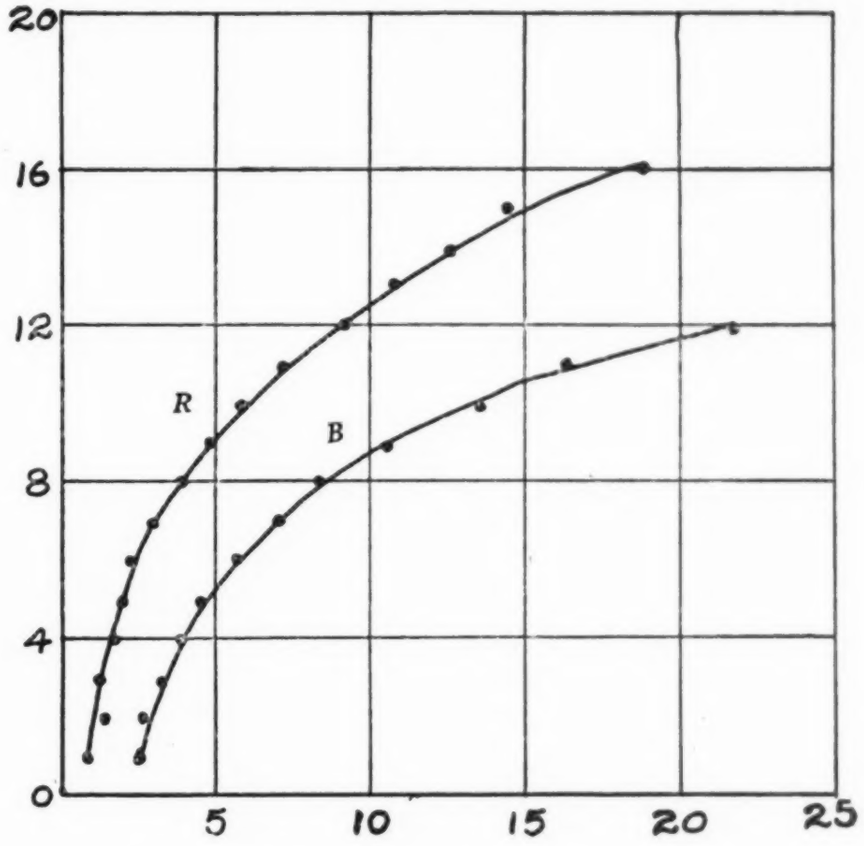


FIG. 3. Showing similar scale for medium intensity.

These results are shown graphically in Figs. 2–4. From the values in column *RD* the sensitivity curve for purple was plotted. A series of points separated by equal intervals is laid off on the sensitivity (j.n.d.) scale (*y* axes), and another series of equally spaced points on the intensity scale (*x* axis). The points of intersection of the horizontal and vertical lines drawn from these respective points in the *y* and *x* axes are the required specifications of the sensibility curve. A complete scale of purples between all red and all blue includes two curves, one for the red end of the purple and the other for the blue end.

The range of individual differences with medium intensity is from 19 to 38 just perceptible purples while the mean variation is 3.2 for the red end and 3.6 for the blue end. For other intensities similar ranges and m. vs. were found.

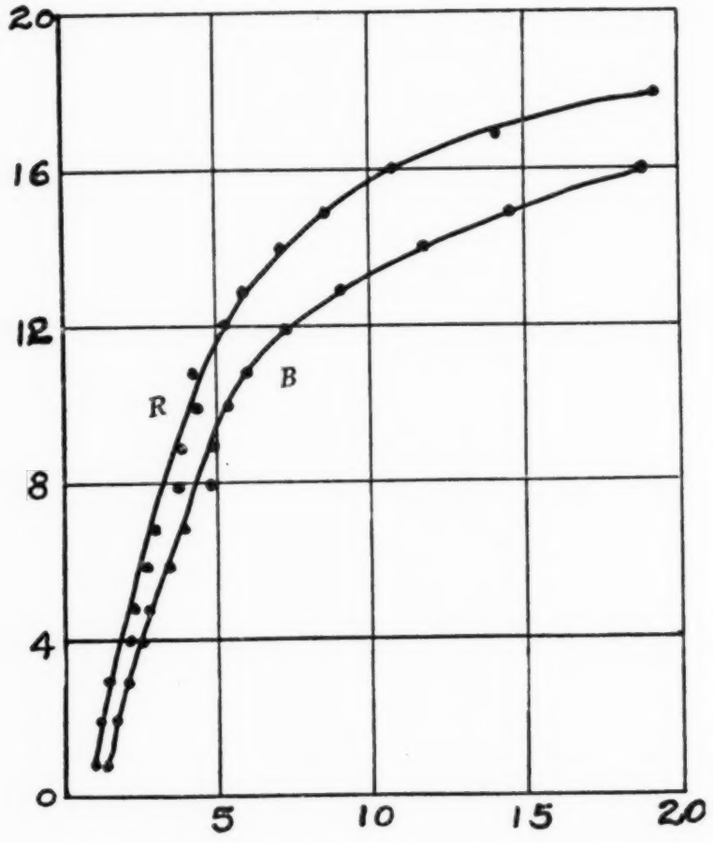


FIG. 4. Showing scale for very high intensity.

Retinal Sensitivity for Red and Blue.—Closely related to the problem of the determination of a scale of just perceptible differences of purple is the question of similar measurements on red and blue when not mixed but measured separately. The determination of such a scale under the conditions of the present experiment is very simple, consisting merely in the measuring off step by step the just perceptible differences of red and of blue from zero to maximum intensity. The results are presented in Table III. and charts 5, 6 and 7.

It will be seen that, excepting the lowest intensity for red, the thresholds of sensity are almost exactly the same for the red and blue components (*i.e.*, the blue and red ends

respectively) of purple as for red and blue when not mixed. At the lowest intensity the sensitivity to unmixed red is .077 as compared with .053 for the red component in the purple. The difference in this case can probably be explained by the influence of the Purkinje phenomenon. That is, the total

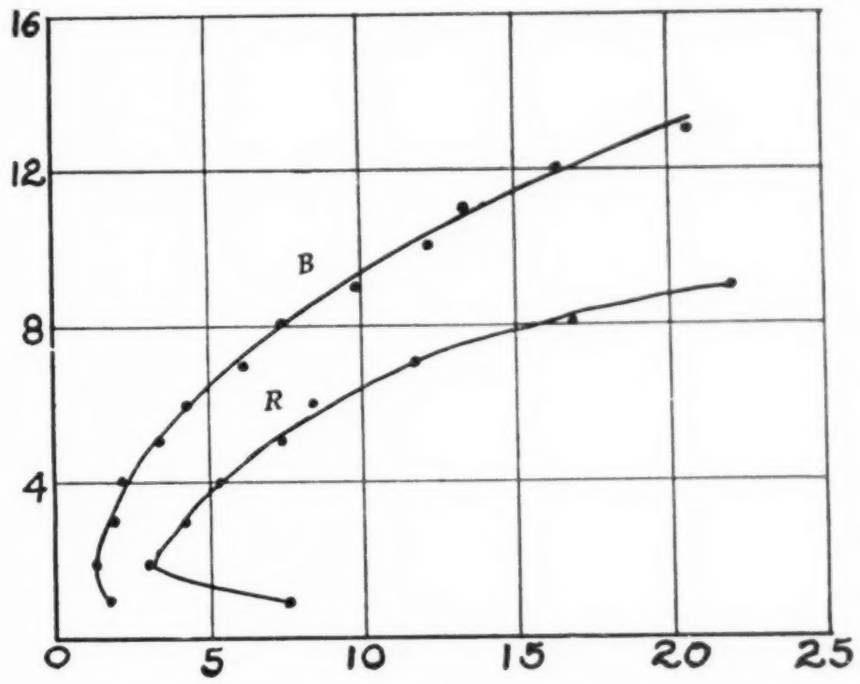


FIG. 5. Showing scale of just perceptible differences of red and blue measured independently. Low intensity.

TABLE III

SCALE OF JUST PERCEPTIBLE DIFFERENCES OF RED AND BLUE FOR LOW INTENSITY

Scale of Red				Scale of Blue			
D	D^2	*R*	*dR*	*D*	D^2	*R*	*dR*
20.0	400.0	.077	.077	9.2	84.6	.0163	.0163
23.6	557.2	.107	.030	12.2	149.0	.029	.013
27.8	773.0	.149	.042	15.4	237.2	.046	.017
32.4	1050.0	.202	.053	18.6	346.2	.067	.021
37.8	1429.0	.276	.074	22.9	524.5	.101	.034
43.2	1866.4	.360	.084	27.4	749.0	.144	.043
49.7	2470.3	.476	.116	32.6	1063.0	.205	.061
56.3	3169.9	.611	.135	38.2	1459.4	.279	.074
64.0	4096.0	.780	.169	44.2	1953.8	.377	.098
72.0	5184.0	1.000	.220	50.8	2580.8	.498	.121
				57.2	3272.0	.631	.133
				64.2	4121.8	.795	.164
				72.0	5184.0	1.000	.205

TABLE III. (*Continued*)

SCALE OF RED AND BLUE FOR MEDIUM INTENSITY

Scale of Red				Scale of Blue			
D	D^2	*R*	*dR*	*D*	D^2	*R*	*dR*
11.8	139.4	.027	.027	7.0	49.0	.009	.009
14.3	204.7	.039	.012	9.5	90.3	.017	.008
17.1	292.5	.056	.017	11.8	139.4	.027	.010
20.5	420.5	.081	.025	14.8	219.0	.042	.015
24.2	585.8	.113	.032	17.8	317.0	.061	.019
28.2	795.4	.153	.040	20.8	432.64	.083	.022
32.5	1056.5	.204	.051	24.1	581.1	.112	.029
37.0	1369.0	.264	.060	28.1	788.6	.152	.040
41.8	1747.4	.337	.073	32.1	1030.3	.199	.047
46.8	2190.2	.422	.085	36.1	1303.3	.251	.052
52.3	2735.5	.528	.106	40.1	1608.1	.310	.059
58.0	3364.0	.649	.121	44.4	1971.6	.380	.070
64.5	4160.5	.802	.153	49.1	2410.9	.465	.085
72.0	5184.0	1.000	.198	54.0	2916.0	.562	.097
				59.5	3520.5	.683	.121
				65.5	4290.5	.827	.144
				72.0	5184.0	1.000	.173

TABLE III. (*Continued*)

SCALE OF RED AND BLUE FOR VERY HIGH INTENSITY

Scale of Red				Scale of Blue			
D	D^2	*R*	*dR*	*D*	D^2	*R*	*dR*
7.0	49.0	.009	.009	8.0	64.0	.012	.012
9.0	81.0	.015	.006	10.0	100.0	.019	.007
11.0	121.0	.023	.008	11.5	132.5	.026	.007
13.0	169.0	.032	.009	13.2	174.4	.033	.007
15.0	225.0	.043	.011	14.9	222.1	.043	.010
17.0	289.0	.056	.013	17.0	289.0	.055	.012
19.0	361.0	.069	.013	19.3	372.7	.070	.015
21.0	441.0	.085	.014	20.8	432.1	.087	.017
23.0	529.0	.102	.017	23.2	538.4	.103	.020
25.5	650.5	.125	.023	25.4	645.4	.124	.021
28.0	784.0	.151	.026	28.0	784.0	.151	.027
31.0	961.0	.185	.034	31.4	986.2	.190	.039
34.0	1156.0	.223	.038	34.7	1204.3	.232	.042
37.5	1406.5	.271	.048	38.7	1467.1	.283	.051
41.0	1681.0	.324	.053	42.0	1764.0	.340	.057
45.0	2025.0	.391	.067	45.8	2089.8	.402	.062
50.0	2500.0	.482	.091	49.5	2450.5	.469	.067
56.0	3136.0	.605	.113	53.0	2809.0	.543	.074
63.0	3969.0	.760	.155	57.0	3249.0	.625	.082
70.0	4900.0	.961	.201	61.0	3721.0	.718	.093
				66.0	4356.0	.840	.122
				72.0	5184.0	1.000	.160

brightness of the purple and hence of the red component is enhanced by the increased brightness of the blue component. The opposite effect is much less marked. That is, the blue component suffers only a slight diminution by virtue of the influence of the low intensity of red in the mixture.

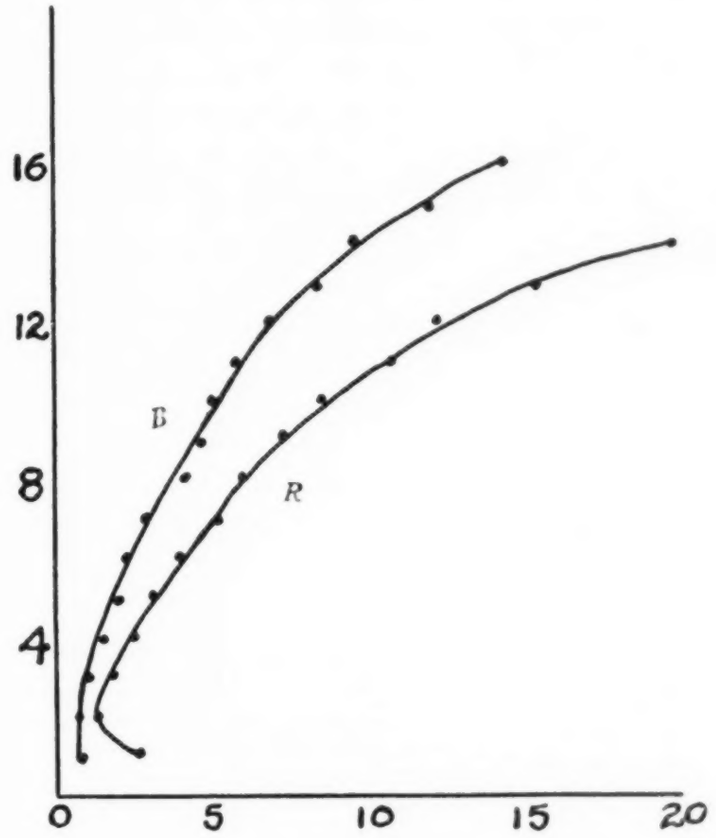


FIG. 6. Scale of red and blue for medium intensity.

The number of perceptible reds and blues is slightly in excess of the number of purples for all three intensities. The form and magnitude of the sensitivity curves for red and blue agree in general with those for the red and blue components in the purple.

SUMMARY

A fairly pure color mixture can be obtained by using Wratten filters and Tungsten lamps. This provides a simple and direct method for the study of purples and other color mixtures when it is desirable to measure the relative proportions of the two components in terms of varying degrees of intensity of a given hue and saturation.

Under conditions of medium intensity of illumination the normal eye is able to distinguish about 28 purples. Of these 16 have an excess of the red component; while 12 have an excess of blue. With low intensity the number is greatly reduced due largely to the Purkinje effect on the threshold of retinal sensitivity to red and blue respectively. With very high intensity a slight increase in the number of observable purples as compared with medium intensity is obtained.

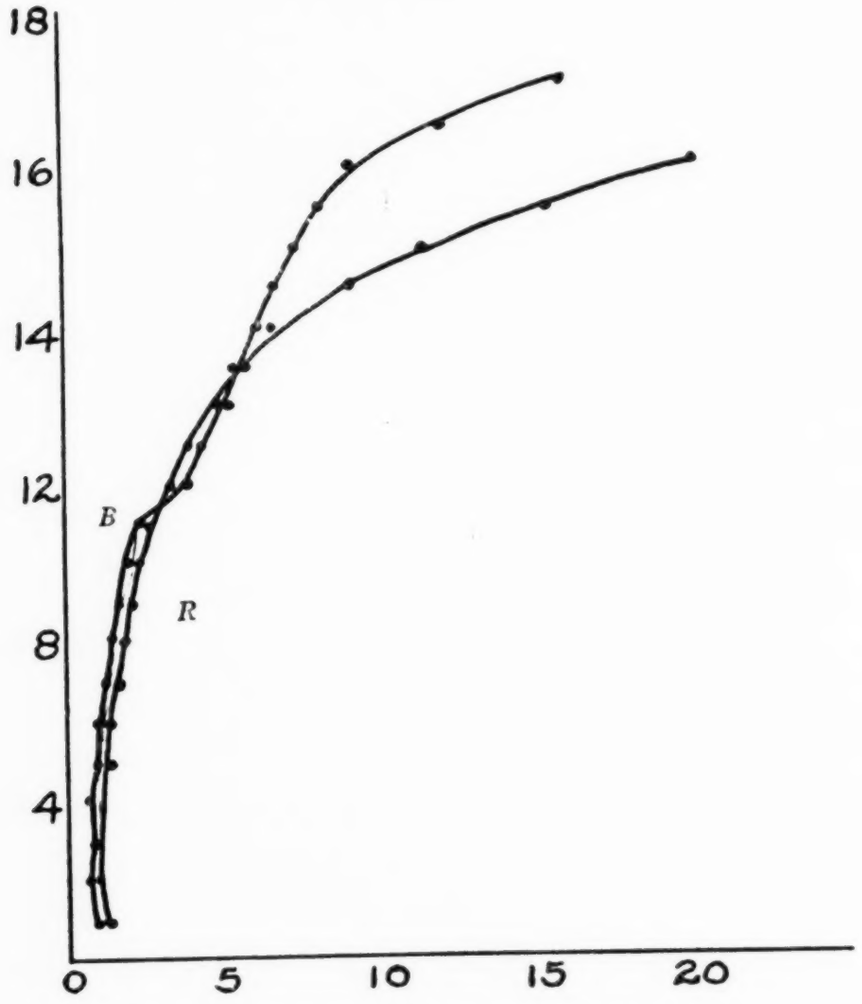


FIG. 7. Scale of red and blue for very high intensity.

A fairly wide range of individual differences in the capacity for discrimination of purples is shown. This capacity agrees closely with the discrimination of red and blue measured independently.

Further Experimental Work

The writer is now perfecting a device for studying purple and other color mixtures [1] by transmitting sunlight through four prisms and cutting out all but the red and blue (or any other components) in the resulting spectra. These colors will then be projected upon a two-part photometer field either part of which can be varied independently by means of adjustible screens across the paths of the red and blue rays, each screen being provided with a narrow slit. The color specification will then be the wave-length units of red and blue in the resulting purple. Results of this experiment will appear in a later number of this Journal.

[1] A spectrum color-mixer has recently been devised by C. E. Ferree which consists of a simple attachment for a spectroscope of the usual type. For brief reference to this apparatus and its uses see *Psychological Bulletin*, *22*, 1925, p. 94.